NOTES OF LECTURES

ON

NATURAL PHILOSOPHY.

FIRST SERIES.

ON

GALVANIC ELECTRICITY.

BY

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CALCUTTA:

PRINTED AT THE BAPTIST MISSION PRESS.

1841.

PREFATORY NOTICE.

THE annexed pages contain the heads of the lectures given in the Medical and Hindu Colleges, on Galvanic Electricity.—In the lectures themselves I entered of course on many additional details, explanations and speculative views which find no place in these memoranda ;—still in their present form and arrangement they constitute a systematic view of the subject quite sufficient for the purposes of the General and Medical Student. I venture to hope too they may prove acceptable to persons of more finished education, who wish to possess some practical knowledge of the broad facts of an interesting and important science without desiring to explore it with mathematical precision.

Should these notes be deemed to fulfil the object of their publication, I propose to issue at intervals of about a month each, a series of similar tracts on magnetism, common electricity, light, heat, the steam-engine and other topics which form the framework of my lectures. The whole series will make a volume of about six or

eight hundred pages, and each number will be illustrated by six copper-plates, such as those now published.

Throughout these lectures I have freely quoted the papers I have myself published on the different subjects discussed, in the Journals of the Asiatic and Medical Societies of Calcutta. I have done so the more willingly as these periodicals are only accessible to a very small proportion of the persons for whose use these lectures are intended.

W. B. O'S.

Medical College, Calcutta,
16*th Jan.* 1841.

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ERRATA.

The reader is requested to make the following corrections with the pen.

Page 32, line 9, from above, for *inferior* read *superior*.

Page 36, line 21, insert at blank 1832.

Page 84, line 8, from below, for *acazus* read *acarus*.

ON

GALVANIC ELECTRICITY.

LECTURE THE FIRST.

I PROPOSE in this course of lectures to give a familiar exposition of the history, effects, and practical uses of the Galvanic Battery. In doing so my object is to enable the reader to prosecute the subject experimentally, and to become thoroughly acquainted with the construction and management of galvanic apparatus. But little acquaintance with other sciences is essential for success in this branch of study. I shall moreover endeavour throughout to explain every circumstance in the simplest manner, and to consider that these lectures are intended solely for the general student, and are not calculated for the information of those who are already adepts in electrical researches.

The magnificence of the experimental phenomena presented by galvanic electricity, the strange and seemingly mysterious effects it produces, the numerous and highly important uses to which it is being daily applied, render its study one of the greatest interest on which persons of general education can engage. It lends us additional encouragement too, when we observe that discoveries in, and practical uses of, this kind of electricity, are being daily accomplished by persons who follow

scientific pursuits but as a source of relaxation from the serious occupations of their lives. The very greatest improvement yet made in the construction of galvanic instruments has been the new battery invented by Mr. Grove, an English barrister, a description of which is given in the sequel. Within the last year too, Mr. Spencer, a private gentleman of no previous scientific celebrity, has shown us a method of applying this power to the copying in copper of coins, medals, reliefs and intaglios, of stereotyping, of obtaining coppercasts of busts and statues, of blocks for wood engravings, and numerous similarly important purposes. The galvanic telegraph and the arrangements for explosions of powder under water have also undergone great improvements and simplification from the ingenuity of persons having but trivial knowledge in other departments of experimental philosophy.

I dwell on these facts chiefly for the purpose of counteracting the impression, too generally prevalent, that to follow this and some similar subjects of study with any practical success, much preliminary knowledge of chemistry and mathematics, or great mental application, and the devotion of much time, are requisite. The reader may be assured that most of this is unnecessary, and that by moderate attention to the facts described in the succeeding pages, a person of average mind and acquirements can construct his own apparatus and so use and apply it as to lead him to results of much importance.

Before noticing the history of galvanic phenomena, it will materially aid the general reader to give a succinct description of a few substances commonly used in these experiments. I do not attempt to describe all the materials which are employed, reserving them for the

sequel of these lectures. To the most important alone we shall now confine our attention.

SUBSTANCES USED IN GALVANIC EXPERIMENTS.

The most important of these are the metals zinc, mercury, copper, gold and platinum, water, membranes of various kinds, the nitric, sulphuric and muriatic acids, the sulphate of copper or blue vitriol, and wires covered with silk. By studying a few of the leading properties of these substances our subsequent task will be rendered of comparatively little difficulty.

Zinc.—Zinc (*dusta,* Beng., spelter of the English markets) occurs in two states, in masses and sheets. The former is very impure being mixed with lead, arsenic and other substances. The latter is of the best quality and that alone should be used in galvanic experiments. The price of rolled zinc in the Calcutta bazar is 25 rupees for 80 pounds weight. Each foot of this zinc weighs eleven ounces. Zinc is greyish, lustrous, crystalline, readily tarnishes on exposure to the air, is slowly corroded by fresh, and very rapidly by salt, water. It melts at a low temperature, takes fire and burns with a fine blue light, combining with the oxygen of the air*, and forms a white oxide of very light spongy texture.

Metallic zinc is rapidly dissolved by the muriatic or

* *Composition of Atmospheric air.* Common air is a compound of two gases, oxygen and nitrogen, in the proportion of one part of the former to five of the second by measure. Oxygen is the constituent on which depends the power of the air to support combustion and respiration, In this gas when pure many substances will burn with splendor, which cannot be inflamed in common air.

sulphuric acids diluted with water. The solution takes place with great bubbling or effervescence. The fluid appears as if boiling, but the bubbles are of an inflammable gas, (hydrogen,) the production of which in this experiment will be understood when the composition of water is explained.

The nitric acid, if concentrated, acts on zinc with excessive violence ; diluted with water, the metal is dissolved with less effervescence than with the acids above mentioned.

If sheet zinc be moistened with a mixture of one part by measure of sulphuric acid and ten measures of water, and be then rubbed over with quicksilver (mercury), the zinc and mercury unite, forming a brilliant amalgam. This amalgam is not dissolved, or at all acted upon, by dilute sulphuric acid. A very small quantity of quicksilver should be used. One ounce by weight will amalgamate both surfaces of 100 superficial feet of sheet zinc. This amalgamated zinc is of great use in the construction of galvanic batteries.

Sulphate of zinc, or white copperas (*sufed tutiya*, Beng.) is a white crystalline substance formed by the action of diluted sulphuric acid upon zinc. It is produced in large quantities during galvanic experiments with zinc. It is used in the arts for increasing the drying qualities of oils, and also in medicine as an emetic and astringent. Its consumption however is not very large. It will yield the metal again by a simple and economical process*.

* Dissolve the sulphate of zinc in rain water and add a solution of carbonate of soda, or of potassa, or of ammonia, so long

In sulphate of zinc there are always present 40.1 sulphuric acid, and of oxide of zinc, 40.3. parts by weight. Oxide of zinc is a compound of zinc 32.3. oxygen 8 parts by weight. These combining proportions are invariable, and accordingly it should be remembered that the equivalent or representative number of Oxygen is, 8

Sulphuric acid,........................ 40.1.

Zinc,............................. 32.3.

or simple multiples of these numbers.

Mercury (*para,* Beng.) is a fluid silver-like metal. It is not dissolved by cold sulphuric acid, either strong or diluted. It is tarnished and acted upon by muriatic acid, and dissolved with violent action by strong nitric acid, more slowly by this acid diluted with water. Mercury unites with zinc forming the valuable amalgam above described. It also combines rapidly with gold which becomes of a white colour and extremely brittle.

Copper (*tamba,* Beng.) is very slowly acted upon by diluted sulphuric acid. The strong acid dissolves it freely, especially when heated. Muriatic acid also dissolves it. Nitric acid acts upon it with great violence; the stronger the acid the more powerful the action, large quantities of a brown acrid and irritating vapour being disengaged.

as a white solid substance is formed; wash this with water, dry it and mix it with half its weight of powdered charcoal and a little oil so as to form a thick paste. Place this in a close clay crucible with a gun-barrel placed as shewn in *fig.* 2, plate 4. By heating the crucible to redness the zinc distills over pure, and may be received in a pan of water.

Gold (*sona,* Beng.) is not dissolved by the sulphuric, nitric or muriatic acids separately, but it dissolves freely in a mixture of nitric and muriatic acid, and in watery solutions of the gas called *chlorine.* From solutions of gold the metal may be recovered by adding a solution of green vitriol (sulphate of iron, *heera kusees* of the bazars) in water so long as a brown precipitate falls. This precipitate washed, dried, mixed with a little borax (*sohaga,* bazar) and melted in a common bazar goldsmith's crucible, yields pure metallic gold without loss. The value of pure gold is 40 rupees the ounce. For workmanship the charge is very trifling.

Platinum is a white metal, extremely dense, perfectly infusible in any furnace heat, can be welded like iron, is not acted upon by nitric, muriatic or sulphuric acids, but like gold dissolves in mixtures of nitric and muriatic acids and in watery solutions of chlorine. From these solutions it is recovered by adding a solution of sal-ammoniac (muriate of ammonia ; *nowshadar,* Beng.) A yellow substance falls which, when dried and heated to redness in an earthen crucible, leaves a spongy mass of metallic platinum. By bringing this to a welding heat, and subjecting it to powerful compression massive platinum is procured, and this may be beaten or rolled into very thin leaves.

Platinum is not procurable as a bazar article. In England its value, unwrought or in foil, is £1,10 shillings the ounce. Its excessive infusibility renders the cost of workmanship in this metal so high that articles constructed from it are usually much more costly than gold*.

* A superficial foot of ordinary platinum foil weighs 2 oz. 25 grains avoirdupois.

Water. This fluid is one of the most important agents in ordinary galvanic experiments.

Water is a compound of oxyen and hydrogen in the proportion of eight parts of the former to one of the latter by weight. In the state of gases, hydrogen being for equal bulks sixteen times lighter than oxygen, the gases obtained by decomposing water are in the proportion by measure of two parts of hydrogen to one of oxygen.

The composition of water is proved by several methods ; for instance,—If the steam proceeding from nine grains by weight, of boiling water, be passed over thirty-two grains of iron filings at a red heat, after the experiment, forty grains of oxide of iron are formed, and about sixteen cubic inches of hydrogen, which weigh exactly one grain. Or by taking thirty-two grains of zinc, nine grains of water and forty grains of sulphuric acid, the water is decomposed, sixteen cubic inches (one grain) of hydrogen gas escape with effervescence ; eight grains of oxygen unite with the zinc ; and the sulphuric acid combines with the forty grains of oxide of zinc, forming eighty grains of the white copperas (sulphate of zinc) above described.

The composition of water is still more beautifully and completely demonstrated by galvanic experiments detailed in the sequel.

Hydrogen gas is the lightest substance in nature, it is extremely inflammable; with half its bulk of oxygen gas, or with $2\frac{1}{2}$ times its volume of common air, it forms a mixture which explodes violently on the contact of a red hot substance, or of platinum sponge, or of the electric spark. By the explosion, water is formed,

and if the experiment be carefully performed in glass vessels, the formation of globules of water may be experienced, and the weight of the water formed, ascertained. The violence of the explosion is so great that very small quantities (two or three inches at most) should be used by inexperienced persons. During the explosion the heat is so intense that platinum, clays, gems, and many other ordinarily infusible substances, melt before it; and some of these, such as lime, evolve during the ignition, a light almost equal to that of the noonday sun. These facts have been applied to the construction of a blowpipe of intense heating power, and to the production of an artificial light of extraordinary brilliancy.

The *Nitric acid* (aqua fortis, *shora-ke-tezab*, Beng.) is the most powerful of all the ordinary mineral acids. It is a straw-colored transparent liquid, specific gravity 1.450, of acrid, irritating smell, excessively corrosive, destroying the skin and clothes, and leaving indelible yellow stains wherever it touches. It is prepared from saltpetre, (nitrate of potash), a compound of 54.2. parts by weight of nitric acid and 47.2. parts of potash, by adding 98.2. parts of sulphuric acid to 101.4. of saltpetre and distilling from a glass vessel. The nitric acid being volatile is obtained in the receiver, and sulphate of potash remains in the distilling vessel. Sulphate of iron *(heera kusees)* may be substituted for sulphuric acid in this process, because it gives out this acid at a red heat. The process however can only be performed in earthen or stoneware vessels, and on a large scale.

The action of nitric acid on the most important galvanic metals has already been explained. On

iron, tin, lead and many others it acts with excessive violence.

The composition of nitric acid is nitrogen (the gas which forms four-fifths of the bulk of atmospheric air), fourteen parts by weight, and oxygen forty, corresponding to one proportion of nitrogen and five of oxygen.

It is to the presence of this large quantity of oxygen in nitric acid that its chemical energies are chiefly attributable. If hydrogen gas in minute bubbles be passed through strong nitric acid, part of the oxygen quits this acid, unites with the hydrogen, and water is formed. This fact is important to be remembered in several galvanic operations.

Strong nitric acid costs in England 2*s*. 4*d*. the lb. and may be prepared in India for 7 annas.

Sulphuric acid (oil of vitriol, *gunduk-ke-tezab*, Beng.) This acid is manufactured on an immense scale both in Europe and in India by burning sulphur with saltpetre in large leaden chambers.

In the concentrated state when pure it is colorless, inodorous, of oily aspect, specific gravity 1.850, extremely acrid and corrosive, leaving a black charred stain behind. Its inaction with gold and platinum and its violent energy when brought into contact with zinc and water have already been described: it dissolves silver at a boiling temperature.

Sulphuric acid is composed of sulphur sixteen, oxygen twenty-four parts, by weight.

This acid is sold in England for 1*d*.; in India for six annas the pound. Diluted with from 10 to 20 fold its volume of water it constitutes one of the chief materials employed in galvanism.

Muriatic acid (spirits of salt, marine acid, *nimuk-ke-tezab*, Beng.) is prepared from common salt (the muriate of soda) by the action of sulphuric acid which displaces the muriatic acid. This is volatile and is condensed by being brought into contact with water. Common muriatic acid is a yellowish and fuming liquid of very acrid, suffocating odour, highly corrosive, though less so than nitric or sulphuric acid. Its specific gravity is 12.56. It is composed of thirty-five parts by weight of chlorine (a simple gas), and one of hydrogen.

In many processes, for instance, when mixed with nitric acid, it loses hydrogen, and the chlorine being set free gives the mixture the power of dissolving gold and platinum. This fact is of importance, as in using batteries of these metals and nitric acid, if the latter is impure, containing muriatic acid, as is often the case, serious loss of the gold or platinum may be sustained. Nitric acid is known to be free from this impurity by dropping a few shreds of gold leaf into a bottle of the acid. If the gold be undissolved it may be used with perfect safety, if dissolved, the acid should not be employed.

Muriatic acid acts rapidly on zinc; hydrogen being disengaged, and muriate of zinc formed in solution.

This acid is not much employed in the processes we have to treat of; but its presence requires to be known.

Sulphate of Copper. (Blue vitriol—*neel tutiya*, Beng.) This beautiful salt occurs in large crystalline masses of superb blue color. It is manufactured and sold in the bazar for 22 rupees for 80lbs. It dissolves freely in water and is composed of copper 31.7. oxygen 8 (together forming oxide of copper) and sulphuric acid 40.1. parts

by weight. If a piece of zinc or iron be introduced into a solution of this salt the iron displaces the copper, which is accordingly deposited instantaneously in the metallic state, sulphate of zinc or of iron being formed instead of the original solution. The fact must be carefully remembered. The sulphate of copper too is readily made to yield its metal by the presence of hydrogen gas. This gas takes the oxygen of the oxide of copper and the metal is left in the uncombined state.

The next class of substances employed are animal membranes, and porous textures of various kinds, such as earthenware, cloth, pasteboard, &c.

Membranes. The bladders of sheep or cows are usually chosen, also the inner membrane of the gullet of the ox. Although the use of pasteboard, or porous earthenware has now superseded that of membranes, still there is a circumstance connected with the permeability of membranes by fluids which requires notice here.

It is well known that many liquids may be confined in bladders or other membranes for a very long time without any perceptible transudation or material loss of the liquid taking place through the pores of the membrane. It has however been discovered of late years, that if a bladder containing a solution of sugar, gum, salt, or many similar substances be placed in a vessel of water, the water penetrates inwards into the bladder and the internal solution passes outwards, but in much smaller quantity. The membrane will finally burst under the distension thus occasioned, or if a long tube be attached to it and kept vertically, the fluid is seen to mount rapidly in the tube and at length to overflow it. This pheno-

menon is beautifully seen by firmly tying a piece of thin membrane, a fowl's crop for instance, round the larger end of a glass cylinder or jar; a small wall-shade answers perfectly. Fill the chamber with syrup and adjust a tube and cork, air-tight to the smaller end, as shewn in the figure. Place the whole in a vessel of rain water and in the course of a few minutes the liquid will be seen to ascend rapidly in the tube. See plate 1, *fig*. 15.

This tendency to penetrate a membrane inwards is termed *Endosmose:* the outward tendency *Exosmose*. The phenomena were discovered and investigated by Dutrochet an eminent French philosopher.

The applicability of these facts will be seen when we treat of Mullins' and Daniell's batteries.

Porous earthenware. Vessels of this kind are now very much used in the construction of galvanic batteries. The common Bengal potters' clay, answers pretty well, and gives a thin, permeable ware, sufficiently porous, and little acted on by strong acids. It is however deficient in mechanical strength and lasts but a short time.

A far superior ware is easily made from three parts of the white *khari* clay of Kolgong and one part of the brown fuller's earth *(saboon mittee)* of the same locality. These earths are to be finely powdered, sifted and made into a paste with water. This paste is very ductile and manageable, and by the common potters of every bazar may be manufactured into vessels of any desirable form. When quite dry these are to be baked at a red heat. They are very permeable, resist acids completely, are firm in texture and last for months though exposed to constant action in contact with the strongest acids.

The last substance I have to describe is the silk-covered copper wire, which is constantly used in these experiments.

The wire may be of every diameter and the longer each piece can be made without cutting or soldering the better. The silk covering is given with unspun silk; the colour is immaterial. In England a machine is used which coats the wire with great rapidity by a pair of revolving bobbins made to rotate very rapidly and deliver their silk on the wire as it passes slowly through a tube in their axis. I have sketched in plate 4, *fig.* 1, the essential parts of such a contrivance, which any one of mechanical turn can easily have made, and by which he can cover his own wires—*a* is a piece of pistol or gun barrel, having a collar *b* on its middle, and made to revolve freely on two supports *c c*, by the wheel and band *d*. The barrel carries the two bobbins of silk also revolving on two bent wires. The wire to be covered *e*, *e*, runs through the centre of the tube guided by two pieces of perforated wood, and may be drawn through at any velocity by the hand, or a wheel, or a weight from the coil, and in the direction of the arrows. It must be kept tense, and as it moves the bobbins are made to revolve round it by working the wheel and band.

By a machine of this kind which can be made up for two rupees in any bazar, several hundred yards of wire may be coated with silk in a few hours by two persons and in one unbroken line, an object of considerable consequence.

The bazar lacemen can coat pieces of wire of from 50 to 300 feet. They cause the whole length of wire to revolve at once and the silk bobbin is kept stationary

in the hand of the workman. It is in fact the reverse of the machine method. The twisting which the wire is subjected to generally causes it to break in many places. To conceal this the workman usually twists the silked ends together, and the wire becomes useless unless this be discovered and perfect metallic contact obtained.

The object of the silk covering is to prevent metallic contact between wires which may have to approach each other closely in galvanic experiments. In Europe some have covered their wires with a resinous varnish. I have tried in Bengal all that have been proposed, and several others, but none have succeeded in withstanding the alternations of the climate, either melting in the hot, or cracking and falling to pieces during the cold season.

Attentive consideration of the few practical facts contained in the preceding pages, and the repetition of the experiments described will render the study of galvanic electricity one of pleasure and ease. Much of the difficulty experienced by those who look to its phenomena for the first time depends on their vague knowledge of the properties of the materials employed in the instruments or experiments they witness.

In the next lecture I shall notice succinctly the history and progress of galvanic electricity, and the construction of the instruments by which it is illustrated and applied.

LECTURE SECOND.

HISTORICAL NOTICE—CONSTRUCTION OF APPARATUS.

The earliest circumstance on record connected with this branch of science appears to be an observation by Sulzer in his *Theorie de plaisir*, that pieces of zinc and silver which are respectively tasteless, if applied one above, the other below the tongue and there made to touch, occasion instantaneously a pungent metallic sensation in the mouth. The "*Theorie*" was published in 1758 and was fraught with a multitude of whimsical speculations we have neither space nor inclination to notice.

We next find it stated that in 1786 a student in the dissecting room of Bologna, having been bitten by a mouse, seized the culprit, killed him and proceeded to dissect him. In doing so, while tracing one of the nerves with the point of his knife, he received a shock which benumbed his arm. The fact excited much attention and was aptly compared to the effects produced by the torpedo and electric eel. No result of value, however, proceeded from the occurrence.

Louis Galvani, to whom in reality the origin of this branch of science is attributable, was born in Bologna in 1737, and was educated for the medical profession. Long before his grand discovery he was distinguished by his success as a profound anatomist. In 1790 during one of his anatomical experiments at which his wife was present, she noticed that convulsions took place in the limbs of some dead frogs, which were placed on a table near an electrifying machine, whenever a spark was taken

from the conductor by a person touching the frog with the point of a knife.

Although this circumstance depends altogether on an effect in common electricity well known at a much earlier period, nevertheless it led to the institution of the experiments by Galvani to which this branch of physics owes its existence. He soon found that by the simultaneous contact of different metals with the muscles and nerves of frogs, fishes, rabbits and other animals, convulsive movements of the muscles were occasioned.

It would be premature to enter on the theory he formed to account for these remarkable effects, and which time and the progress of science have completely subverted. Suffice it to say that his views were warmly opposed by the illustrious Volta, who in 1797 published the results of his numerous experiments in the XIVth vol. of the *Giornale fisico-medico* of Brugnatelli, having, however seven years previously, addressed an account of his discoveries and apparatus to Sir Joseph Banks, then President of the Royal Society of London.

The first regular apparatus was that invented by Volta and still called Volta's pile,—(see plate 1, *fig.* 1.) It consists of a number of plates of copper and zinc, of which two were joined together, then a piece of pasteboard placed above, having been previously soaked in salt water or dilute muriatic acid. Similar sets were piled on each other, observing the same order throughout, that is, that all the zinc surfaces, and copper surfaces should present in the same direction. Ingenious as was this arrangement smart shocks and faint sparks were the only effects it induced. The Medical College possesses an instrument of this kind of 200 disks, 3 inches in diameter, and the effects are far inferior to those of a

modern arrangement not larger than a single disk of this series.

Volta about the same period also constructed the apparatus called the "crown of cups." It was composed of sets of zinc and silver rods soldered together and bent into an arch so that the ends of each pair dipped in separate glasses, containing very dilute acid. In this arrangement the zinc of one couple occupied the same glass with the silver of the second and so on. The first zinc and last silver were not immersed but were attached to copper wires ending in gold points. These wires were called the *conductors* and their ends the poles of the battery.

In 1800 Messrs. Nicolson and Carlyle of Woolwich made the remarkable discovery of the decomposition of water by this new agent. These experimentalists found that when the gold or platinum terminations of the battery were immersed in water at a moderate distance apart that a stream of gas issued from each point. The gases were collected separately and found to be hydrogen and oxygen, the former in the proportion of two measures to one of the latter. Each gas was uniformly given off at the same side of the battery, and although very minute quantities only were obtained their distinctive properties were unequivocally ascertained.

In the same year Mr. Carlyle further decomposed several neutral salts, for instance, the sulphate of soda, and found that the acid went to one pole, the alkali to the other, the order being constant. He further noticed that oxygen and the acids were given off at the same side, and hydrogen and the alkalies at the other.

In 1801 Mr. Cruikshanks of Woolwich, constructed the trough battery which bears his name, and of which

specimens may be seen in all cabinets of philosophical instruments. It consists of a trough of wood rendered water-tight by cement, and subdivided by metallic plates into cells half an inch broad. Each plate was formed of a zinc and copper plate soldered together by their surfaces. All the zinc surfaces were disposed in one direction, all the coppers in the opposite one. (See plate 1, *fig.* 2.) This battery was charged either with a solution of sal ammoniac or with very dilute muriatic acid. Though superior in power to the previous forms of apparatus it still gave very insignificant results. It was imitated with slight modifications by several experimentalists. The plates, for example, were attached to a movable wooden bar so that they could be immersed in the cells and removed from them simultaneously without delay.

Soon after this period Sir Humphrey Davy commenced his memorable researches. His first important discovery was that electric arrangements might be made by single metals having two surfaces, each acted on by a different chemical agent. He succeeded in decomposing ammonia, nitric acid and several salts. In all these experiments the acid formed round the wire corresponding to the zinc surface, and the alkali round the wire of the copper surface. By various experiments it was found that the former was in an electric state similar to that of *positive*, while the copper surface answered to the *negative* common electricity. But the discovery which rendered Davy immortal was his succeeding in decomposing by the galvanic battery the alkalies, potash and soda, and proving these to be compounds of oxygen with metals of the most extraordinary properties. These metals are lighter than water, take fire on its surface; nay, that

obtained from potash inflames when brought into contact with ice. Pursuing this superb train of discovery he decomposed, and obtained similar metals from, lime, magnesia and other earthy bodies. The battery with which these wonderful results were obtained consisted of 2000 couples of zinc and copper, each plate four inches square, arranged in porcelain troughs and acted upon by dilute sulphuric and nitric acids. Besides its chemical effects it was found to give overwhelming shocks, to deflagrate and burn metallic wires, and that when its poles were tipped with charcoal their contact occasioned the ignition of the charcoal and the emission of light of inconceivable brilliancy. On slowly separating the poles an arch of electrical flame $\frac{3}{4}$ths of an inch long extended between them, and on repeating this experiment in the vacuum of an air-pump the arch of flame could be lengthened to three inches, and it was discovered to be attracted or repelled by the different poles of a steel magnet brought into its vicinity.

This formidable battery however was too sudden and inconstant in its action to be used with the calmness essential for the complete investigation of the laws of the arrangement. Various attempts were therefore made to render the instrument more constant and more manageable in the hands of ordinary manipulators.

The first great improvement introduced was by Dr. Wollaston in 1805. The construction of his battery is shewn in plate 1, *fig*. 3. Each element or couple consists of a rectangular plate of zinc, surrounded by a plate of copper at half an inch distance, and kept from contact by slips of wood. The zinc of one plate leads to the copper of the next, and so on through the whole arrangement. Ten couples form each set, and are attached to a

wooden bar by which they are immersed in the corresponding cell of a porcelain trough.

Ten plates of this construction each 6 inches square, suffice to shew the decomposition of water and of several of the neutral salts—to produce sparks—to ignite and fuse thin pieces of platinum or steel wire, and to occasion some magnetic effects which will subsequently be pointed out.

It having been ascertained about this period that increasing the *surface* of the plates increased proportionally the igniting and heating powers of the battery, a very remarkable arrangement was constructed by Mr. Children of London in 1815. His battery consisted of 20 spiral coils of zinc and copper sheets, the copper being 2½ feet broad and 6 feet long. The metals were kept from contact by horse-hair ropes.

Twenty of these couples were arranged in the usual way, the copper of one being connected with the zinc of the second, and so on. The whole of the coils were suspended from a beam and lowered at pleasure into cisterns of dilute acid placed beneath them. The igniting effect of this arrangement was so great that it fused bars of platinum ⅜ of an inch thick.

All experimentalists were however surprised to find that it gave no perceptible shocks. This fact was soon followed out and it was found that to affect the living system, or produce muscular commotions, a series of several small couples not larger than one inch disks are more effective than a few plates however enormous their size.

About this time (1819) Oersted of Copenhagen made the great discovery of the magnetic state of a wire connecting the elements of active galvanic circles. This

discovery in itself opened out a wide field of science and disclosed the existence of a new force previously unsuspected by philosophers. The fruitful applications in art and science to which it has led will give us an interesting object of study as we proceed.

Professor Hare of Philadelphia in subsequent years constructed several series of batteries on Children's plan, and succeeded with them in producing some remarkable effects. He was the first to shew how platinum wires could be ignited at a great distance and even under water, and to propose the application of this fact to submarine explosions. The success which has attended the practical application of this plan to the destruction of sunken wrecks, and on the very largest scale, has been sufficiently shewn by the explosions conducted by Colonel Pasley, Captain Fitzgerald and myself.

In 1832 and succeeding years, Mr. Faraday, in a series of masterly papers published in the Transactions of the Royal Society, investigated minutely many of the laws of the galvanic circle, added several most important facts to our knowledge, and enriched the nomenclature of the subject with numerous terms singularly expressive and appropriate and since universally adopted. These terms will be quoted and explained as we proceed.

The first step towards accomplishing the desideratum of a constant battery was afforded by Mr. Kemp's discovery in 1829 of the remarkable fact that amalgamated zinc (see page 3), is not acted upon by dilute sulphuric acid unless it forms part of a galvanic circuit. As most of the recent and extraordinary improvements in the battery depend upon this fact, we must endeavour to place it before the student in a plain and practical light.

Let a piece of well amalgamated zinc be immersed in a glass vessel containing sulphuric acid one part, water twenty. No action whatever occurs. Introduce a gold or platinum wire without touching the zinc, there is still no action. Let it touch the zinc and immediately a copious stream of hydrogen gas issues from the wire. Water is decomposed the instant of the contact. Its hydrogen escapes from the platinum wire, its oxygen unites with the zinc, and immediately after on removing the platinum wire we find oxide of zinc in solution.

Or let the zinc and platinum be immersed in the same acid but not touching each other. Then let a wire touch each simultaneously out of the fluid (see plate 2, *fig*. 1), the same instantaneous decomposition of water occurs, and continues to take place so long as the metallic contact is established, ceasing the instant this is interrupted.

If a series of couples of platinum and amalgamated zinc be arranged on the plan of Volta's crown of cups until metallic contact is established between the first zinc and last platinum of the series no action takes place on any of the zinc plates. On the contact being made decomposition of water proceeds in every cell, hydrogen is evolved on each platinum plate, each zinc plate is oxidized; and the measure of hydrogen is the same from each platinum, and the amount of oxide of zinc formed the same in each cell. All action ceases in the entire series when metallic contact is interrupted in any part of its course.

This arrangement would answer every purpose were it not for two objections. In the first place the sulphate of zinc (produced by an electrical action afterwards explained) deposits metallic zinc on the surface of

the platinum plate and all electrical action is thereby soon nullified, there being only zinc surfaces opposed to each other. Secondly, the hydrogen gas set free in bubbles from the platinum surface is found to intercept or prevent much of the electrical effect. After Kemp's discovery there thus still remained these two capital faults before the galvanic battery could be deemed a perfectly manageable or constant instrument.

Mr. Mullins, M. P. for Kerry was the first who succeeded partially in remedying these evils. In his battery a copper cylinder was surrounded by a bladder, outside which was placed an amalgamated zinc plate, the whole immersed in an earthen vessel. A series of any number of these was combined by leading a wire from the zinc of one to the copper of the second, and so on. The battery was charged by filling the copper cylinder with a strong solution of sulphate of copper, and pouring a solution of salt or weak sulphuric acid on the zinc outside the bladder.—See plate 2, *fig.* 5.

In this battery no action occurred unless the first and last metals were united by a metal, by charcoal or by some conducting substance. Decomposition of water took place on the zinc side, and the hydrogen transferred through the bladder being set free on the copper side in presence of sulphate of copper reduced the oxide of that metal, which was accordingly deposited in thin bright layers on the surface of copper opposite to the zinc. An equivalent quantity of sulphuric acid also passed through the membrane from the copper to the zinc side, where it formed sulphate of the oxide of zinc. But though the membrane effectually prevented the passage of metallic *zinc* to the copper, it has always been found in practice with these batteries that the opposite fault occurs and

copper is gradually deposited on the zinc. This constitutes their most serious defect.

Professor Daniell's batteries are nearly on the same plan. An amalgamated zinc rod is surrounded by membrane and immersed in a copper cylinder containing a strong solution of sulphate of copper. The zinc is acted upon by diluted sulphuric acid.

Among the objections to the use of membranes was their rapidly spoiling and being corroded, and their not permitting the use of any but the circular or cylindrical form. To obviate these faults I tried in 1839 with full success the use of tanned sheep skin and subsequently of pasteboard. The use of this article gives us unlimited command over the form of the battery, while it is less troublesome and more lasting than membranes of any kind.

On this plan I constructed in 1839 two sets of batteries which require a cursory description.

One set consisted of 80 rectangular troughs (see plate 1, *fig.* 8), 14 inches long, 13 deep, one broad. For each trough there was a corresponding zinc plate amalgamated and enclosed in a pasteboard, case (see *fig.* 7) the edges of three sides being fastened water-tight by slips of wood and copper screws.

Ten of these cells effected constantly a greater degree of chemical decomposition than would have been caused by treble the number of the previous arrangements. The igniting effects too were so powerful as to enable me to use this small number with confidence and success in the explosion of the wreck of the Equitable at Fultah Reach in the Hooghly on the 14th December, 1839.

The whole series of 80 constituted the most powerful battery then in existence. Its effects will be noticed in the sequel.

The second series above alluded to consisted of 12 water-tight teak cisterns, each of an internal area three feet long, two deep, and three inches wide. Each cistern was provided with two copper partitions, at an inch distance from each other, thus dividing the cistern into three metallic cells each exposing 12 feet of copper surface. Between each pair of copper surfaces a zinc plate of corresponding size was introduced in a paste-board case. Thick copper wires led from each zinc to the copper plates of the adjacent cistern. The battery thus exposed thirty-six feet of active surface in each cistern. It was charged by a strong solution of sulphate of copper in contact with the copper, and of sulphate of soda in contact with the zinc. The chemical, magnetic, heating and igniting powers of this splendid instrument exceeded all I had ever witnessed or read of. They are described in detail in subsequent lectures.

We now arrive at the last and greatest step to perfection in this apparatus, by which the chief faults above pointed out are remedied, and which, while it opens prospects of still greater success, at once places the galvanic battery among the most constant, portable, manageable and powerful of all the instruments which science has given to mankind.

Mr. Grove, an English barrister, is the contriver of this most original and valuable apparatus. The elements consist of amalgamated zinc and platinum, separated from each other by porous earthenware cells. In contact with the platinum is placed the strongest nitric acid. In contact with the zinc, a mixture of one part sulphuric acid and ten parts water.

No action whatever occurs in this arrangement till the extreme plates are united by a conductor. Water is

then decomposed as in all the other cases—and its hydrogen being transferred through the porous earthen cells to the platinum is there intercepted by the nitric acid with which it gradually forms water, thus diluting the acid.

The platinum undergoes no change whatever—the battery is perfectly constant in its action. Its powers are so enormous, that by tests which will subsequently be explained, it has been proved that ten such couples, each four inches square are equal in power to more than thirty-eight times that surface of the best previous construction of zinc and copper.

On this principle, using (for local reasons merely) gold instead of platinum, I have prepared a battery of forty-eight couples, of which the following is an exact description.

Each couple consists of two zinc cylinders and one gold cylinder, which with the porous earthenware vessel fit in a pint glass tumbler. All the parts are shown in plate 1, *figs.* 9 to 14.

The gold cylinder is two inches broad, four deep, and is provided with a gold strap half an inch broad and three inches long. It is placed in the circular cell formed by the two concentric walls of the earthenware cylinder (*fig.* 12), and this is filled with the strongest nitric acid. In the centre is placed the small zinc, outside all the large zinc, and the straps belonging to these are bent in contact with each other, between them being placed the gold from the next cup, the contact being preserved by a little copper spring clasping the straps together like a finger and thumb. In contact with the zincs is poured the usual mixture of sulphuric acid and water.

In electric power this battery equals for equal surfaces those of Mr. Grove's platinum cells. The effects produced

will be given in detail. I should mention here however that I have found by recent experiment that well gilt porcelain produces exactly the same effect as gold, and I have accordingly sent orders to France for fifty cylinders gilt at both sides and each exposing two superficial feet. I have also found that a mixture of two parts by weight of sulphuric acid to one of saltpetre gives as effective a liquid for the gold surface as the strongest nitric acid. These facts render the gold battery in construction as cheap as those of copper, and in sustaining action much more so, inasmuch as the expense of the mixture I describe is not more than one-third of the solution of sulphate of copper. The importance and utility of these facts will be apparent as we study in detail the effects of the galvanic agent.

The gold of the battery above described is worth about £500.

LECTURE THIRD.

NOTICE OF COMMON ELECTRIC EXCITEMENT—ON THE CHEMICAL EFFECTS OF SIMPLE AND COMPOUND BATTERIES.

In the two preceding lectures I have noticed the materials used in the construction and working of the galvanic battery in its various forms, and in connexion with a rapid historical notice, I have at the same time, described the various kinds of batteries in use and the general effects they occasion. We now proceed to examine these effects with more minuteness, and we shall accordingly consider in succession the chemical, magnetic, igniting and physiological phenomena they exhibit. It is

first expedient to afford the general reader a rapid glance at the effects which common electricity occasions.

When a piece of wax or a dry glass tube is subjected to friction on woollen cloth or silk, it is found to attract and repel light substances, such as feathers, dust, pith-balls, metallic particles and the like. In studying these facts we further find that a substance attracted by the excited glass after touching the latter is repelled, while excited wax attracts it; or on the other hand whatever excited glass attracts, the wax repels. A great multitude of substances can assume this excited state, and if it agree in attracting power with that of glass it is termed *vitreous*, if with that of wax, *resinous* electricity. Large surfaces of glass or resin subjected to friction by machinery are found to give powerful sparks, which pass suddenly with various tints and often present the exact appearance of lightning on a miniature scale.

The electricity excited by friction may be conveyed by certain bodies termed *conductors* to great distances from the source of excitement. The metals, dry charcoal, dilute acids and saline solutions, water, and moist air are the best conductors; and among the metals copper holds the first place. The electricity which is being conveyed has been proved moreover to affect only the surface, not the mass of the conductor.

There are again numerous substances which refuse to convey electricity along their surface and are therefore called non-conductors; or, being sometimes employed to confine it or restrain its progress, *insulators;* of these glass, sulphur, resins, lac, caoutchouc, silk, talc and oil of turpentine are the most remarkable.

The two opposite conditions we have described as

vitreous and *resinous* are also termed *positive* and *negative,* on the idea that the phenomena of rubbed glass depend on an excess, those of excited wax on a deficiency of their natural electric matter. The fact however that two negatively electrified bodies repel each other is in itself sufficient to disprove the latter hypothesis, inasmuch as it involves the conclusion that the particles of matter in the natural state are self-repellent.

When a substance *a* in a state of electric excitement is brought into the vicinity of a conductor placed on an insulating support, the part of the conductor nearest *a* is found to be electric, but in the opposite kind of excitement, while the part most distant from *a* is also electric, but the excitement is of the same kind. These phenomena are called *induction.* On withdrawing *a* all evidence of electrical activity ceases in the second body. But if we touch it at the part most distant from *a*, while under induction, a spark of the same kind of electricity passes to the finger, and then on removing *a* the second body remains in the active state but in the opposite condition.

These facts have been applied to the accumulation and preservation of great quantities of electricity in the apparatus called the *Leyden phial.* This consists of a bottle having tin foil pasted on its inner and outer sides to within two inches of the top. A wire terminating in a ball is in contact with the outer coating and rises above the bottle passing through a piece of glass for its support.

On passing sparks say of vitreous electricity to *a,* the inner coating acquires the vitreous state, and acting by induction on the outer metallic coating *b* the natural electricities of this are decomposed, the vitreous or positive is repelled to the outermost surface, the resinous or

negative attracted to the surface next the bottle. The finger brought near the tin foil receives a succession of sparks, and on withdrawing the finger the jar remains charged, the inner coating being in the vitreous (positive), the outer in the resinous or negative state.

If any conducting body be interposed between *a* and *b*, the two electricities rush together, often with an explosion, and if an animal be the conductor violent shocks are experienced. If the discharge be passed through a very fine wire it is melted and dispersed. It inflames various substances, and in short presents all the phenomena of lightning in a minute degree. It magnetizes steel needles if discharged *across* them, and by very careful management it effects chemical decomposition.

A series of Leyden bottles may be arranged so as to form a "Battery." This may be charged by the common electrifying machine, by the electric fluid attracted from the clouds, by electricity evolved from jets of high pressure steam, by magnetic instruments, and lastly by the *galvanic circle*. It may be charged to such a degree that the explosions resound like musketry, and take place with force sufficient to destroy the life of the largest animals.

This slight sketch of common electricity is essentially necessary for understanding the sequel of these lectures. We now proceed to notice the chemical effects of the galvanic agent.

CHEMICAL EFFECTS OF THE GALVANIC CIRCLE.

To study these with success we should learn the properties of a few substances much used in the experiments necessary to illustrate the subject. The mineral acids, water and some metallic and saline substances have

already been noticed. The reader is further referred to my Manual of Chemistry for additional information regarding these articles.

Expt. 1. Take a single couple of amalgamated zinc and copper, excited by dilute sulphuric acid, see plate 2, *fig.* 1. Let a copper wire lead from each terminating in a platinum point. Place a drop or two of water in the little glass capsule plate 2, *fig.* 2, and introduce the platinum points so as not to touch each other. No action takes place.

Expt. 2. Take one of the gold cells, plate 1, *fig.* 13, and dispose its wires similarly. There is still no action.

Expt. 3. Add a drop of sulphuric acid to the capsule, or a minute crystal of salt (common or Glaubers salt) and again try the couple, *fig.* 1. There is no effect visible. But with the gold and zinc couple, a stream of gas rises from each of the platinum points.

Expt. 4. Repeat experiment 1st, with a single cell of any size (say one of the thirty-six feet cells of the College battery). The same effect is observed.

From these experiments we conclude that the decomposing force of a single cell is not in proportion to its surface or size, but to the energy of electric action within it; and secondly, that water containing a little acid or saline matter is decomposed under circumstances when pure water is not affected.

A single cell of whatever size or construction has indeed but very faint decomposing force. The whole of the gold battery of forty-eight cells can be arranged so as to act as one cell, and still this occasions little greater chemical action than $\frac{1}{48}$th part of the series would accomplish.

Let us now see the effect of adding to the number of

cells and confine ourselves at first to the study of the decomposition of water. For these experiments the apparatus, plate 3, *fig*. 2, is occasionally used. It consists of a glass cup with two inverted tubes, to be filled with water slightly acidulated, and placed over strips of platinum foil which can be connected with the ends of the battery outside. The gas evolved passes into the tubes.

Another and far inferior instrument is shewn in plate 3, *fig*. 5. It consists of a glass jar to which a cork and bent tube are attached. Two platinum or gold plates (the gold must be perfectly pure) are introduced, with straps or thick wires of the same metal led (air and water tight), through the sides of the jar. The jar is filled with water acidulated with sulphuric acid. On making connexion with the battery, decomposition rapidly occurs and the gas produced is delivered by the tube into the graduated jar, *fig*. 5, standing over water, and thus the quantity produced in a certain time is measured with the greatest ease.

The following table shews the effect of increasing the number of couples in the battery. The apparatus used was a series of three hundred cells on Mullins' construction. In each experiment the gas was collected for three minutes.

Number of cells.		Gas obtained in cubic inches.
1	....	no effect.
2	....	0.30
4	....	3.90
6	....	6.00
8	....	6.60
10	....	7.80
12	....	9.00
14	....	9.60

Number of cells.		Gas obtained in cubic inches.
16	....	9.90
18	....	10.20
20	....	10.50
22	....	9.60
32	....	9.00
42	....	7.50
52	....	6.90
62	....	6.90
86	....	6.90*
106	.....	7.80*
146	....	8.10*
300	....	7.80

* The increase here was owing to the temperature of the battery becoming higher from the heat of the day.

Thus beyond the tenth additional pair the chemical force of this battery did not increase with any number of additions.

In another set of experiments the rectangular cell battery similarly charged was employed. The surface of each zinc plate in this arrangement is greater than that of the last experiment. The time was the same, three minutes for each trial.

Number of cells.		Cubic inches of gas.
1	....	0.00
2	....	2.50
3	....	5.20
4	....	9.00
5	....	12.00
6	....	24.00
7	....	31.00
8	....	40.00
9	....	43.00
10	....	46.20
11	....	48.00

Number of cells.	Cubic inches of gas
12	50.10
24	56.00
30	58.00
40	59.30
60	61.70
80	62.00

These experiments shew that increase of surface of each cell increases proportionally the decomposing force, but that no *proportionate* increase resulted from adding to the series of these cells beyond the sixth of the series.

The same experiment was tried with the thirty-six feet cistern battery.

Number of cisterns.	Gas obtained in 3 minutes.
1	0.00
2	7.00
3	21.00
4	43.00
5	74.00
6	140.00
7	210.00
8	220.00
9	220.00
10	224.00
11	225.00
12	227.00

Here we again observe beyond the seventh addition no proportionate increase of decomposition. In this experiment too we observe a smaller quantity of gas formed than we might expect from the immense size of the plates. This proceeded however chiefly from the inadequacy of size in the decomposing plates of the voltameter which must always be enlarged in proportion to the size of the galvanic or active surfaces.

Lastly with the gold battery we have found the following results.

Gold cells.		Cubic inches in three minutes.
1	....	a trace.
2	....	3
3	....	11
4	....	18
5	....	21
6	....	23
7	....	27
8	....	30
9	....	32
10	....	32
12	....	34
14	....	37
16	....	39
18	....	39
20	....	39
25	....	40
30	....	41
35	....	42
40	....	42
48	....	42

Thus this battery is for an equal number of cells (four of Mullins') five times more powerful than one of six times greater surface, but it still shews the influence of the same law that beyond the addition of a few couples the decomposing effect is not proportionately augmented.

It is now time to draw the reader's attention to what occurs in the battery itself during the decomposition of water in the apparatus, plate 3, *fig.* 5.

We have already described the composition of water, and must now repeat that nine grains of water contain eight of oxygen and one of hydrogen gas, and that nine

grains of oxygen at common temperature and pressure measur, 26 cubic inches, and one grain of hydrogen 52 cubic inches. Thus 78 inches of gas in the voltameter shew that one equivalent of water has been decomposed.

I have already explained that decomposition of water occurs in each of the battery cells, and that oxide of zinc is formed and dissolved by the sulphuric acid. Now it is found by experiment that for every equivalent of water decomposed in the voltameter thirty-two grains of zinc are oxidized and dissolved from every zinc plate in the series.

Thus in the experiments with the eighty rectangular cells, 8 plates decompose an equivalent of water in 6 minutes, at the expense of 8 equivalents of zinc or two hundred and fifty-six grains. But eighty cells only effect this decomposition in about 4 minutes and at the expense of eighty equivalents or two thousand five hundred and sixty grains of zinc.

This most important law was discovered by Mr. Faraday in 183 , and it applies to every form of battery yet invented. It may be thus expressed : " For every equivalent of a compound decomposed in the voltameter an equivalent of zinc is corroded from every zinc in the whole series."

Various circumstances may *increase* the expenditure of zinc, but it seems that less than the equivalent cannot under any circumstances be consumed from each plate.

The best, most powerful and cheapest chemical battery therefore is that which with fewest alternations of zinc decomposes an equivalent of water in the shortest time.

It is here necessary to observe that in those forms of apparatus in which more than one zinc plate is used in

the same cell, provided these plates be in metallic contact they act as one. Thus the three large plates in each of the teak cistern batteries, and the two of the gold cells being connected together act as one plate. The loss of zinc therefore from the three great zincs is one-third of an equivalent from each, and from the two zincs of the gold battery, half an equivalent from each.

We learn further from the voltameter that within certain limits increasing the surface of the plates increases in direct proportion the decomposing power of a given series. Thus four of the gold cells evolve 18 inches of gas in one minute. If we then join all the zincs of two cells together, and also unite the golds, and then connect four of these double cells in the usual order, the result is exactly doubling the decomposing power, or in other words obtaining 36 inches of the mixed gases.

This holds exactly true as far as two feet active surface in the gold batteries, and six feet in the copper arrangement. Beyond that the subject is still open to investigation. In the following tables are recorded the results of experiments on this point conducted with batteries of Mullins' and my own construction.

My first experiments consisted in introducing a second cylinder of zinc covered with a membrane, into the copper cylinder of Mullins' battery. Both surfaces of the copper were thus called into action.

The following was the result of the comparative trial:

Single zincs, surface	60 inches,	in 3 min.	gave	10 in. gas.
Double zincs,....	120	 3	....	20 do.

Following up this observation, a battery of 12 cans, each consisting of three concentric coppers and two concentric zincs, each plate provided with a membrane,* was constructed so that the series of coppers exposed a

surface of 240 inches. Again the decomposing force was exactly doubled, thus:

Single zinc cans, surface	60 in. in	3	min. gave	10 in.
Double ditto, ...	120	3	....	20
Concentric nest, ...	240	3	....	40

With the rectangular batteries, a copper partition 16 inches by 14 was introduced into the middle of each cell, and a zinc plate placed at each side. The surfaces were thus doubled, and the effects were immediately doubled also.

5 single cells gave	13	inches in	3 min.
5 partitioned do.	30	....	3
8 single do.	35	....	3
8 double do.	70	...	3

Twenty-four single cells were now arranged, so that they constituted eight sets. Thus every three copper cells were placed in metallic contact, and the wires of every three zincs led to the adjacent triple copper.

These eight triple cells gave in three minutes, 106 cubic inches, the exact arithmetical ratio which tripling the surface should occasion.

Influence of temperature on the decomposing force. This point is of so much importance that it requires full experimental illustration. The following results I repeat from a paper I published on this subject in the Quarterly Journal of the Medical Society of Calcutta, 1838.

The temperature of the period during which my first experiments on this subject were carried on, viz. from the 10th April to the 30th of June, ranged from 84° to 100° Fahr. in the room where the batteries were used.

The daily variation of power in Mullins' constant battery with new plates, and strong solutions, was from 5 to 7 cubic inches, from 10 A. M. to 4 P. M.

The range of effect in a large rectangular battery subsequently described, was 33 to 42, during the latter end of July and whole of August, while the Thermometer in the laboratory varied from 78° to 92°.

To ascertain the effect of artificial changes of temperature, the following experiments were tried.

On the 16th August I placed in a cistern of water a battery of eight rectangular cells, which in air and in water at 88° evolved at its poles 22 inches of gas in three minutes. By adding boiling water in successive portions to the cistern, the temperature of the battery was gradually raised, and its decomposing powers tried. With every increment of temperature the force of the battery augmented, and at 130° Fahr. it was more than doubled as is seen in the annexed table.

Temp. of battery.		Gas evolved.		In
86	....	22 cub. inches.		3 min.
90	....	27	....	3
93	....	31	....	3
97	....	34	....	3
102	....	36	....	3
105	....	39	....	3
107	....	40	....	3
120	....	45	....	3
130	....	48	....	3

The warm water was now drawn off and the battery allowed to cool gradually. The force proportionately and regularly fell. Thus:

Temperature.		Gas evolved.		In
126	....	40 cub. inches.		3 min.
120	....	39	....	3
116	....	36	....	3
112	....	35	....	3
92	....	30	....	3
86	....	24	....	3

In these experiments then we find, that the range of heat from 84 to 102 is more than sufficient to produce the daily variation of galvanic power I have noticed.

On the 17th August these experiments were repeated with a more powerful battery, and the preceding results were thoroughly verified; thus:

The battery employed consisted of 8 rectangular cells, of the same dimensions as in the preceding experiment, but having newly amalgamated zinc plates.

Temperature of the battery.		Gas evolved.		In
80	....	40 cub. inches.		3 minutes.
83	....	46	....	3
96	....	80	....	3
100	....	93	....	3
130	....	120	....	3
140	....	136	....	3
150	....	159	....	3
160	....	180	....	3

The battery in these experiments was heated by immersion in water. Those who are conversant with galvanic phenomena would have been gratified to witness the effect produced by so small a battery. It occupied little more than a cubic foot of space. Its heating and deflagrating powers were great in proportion to its chemical force. On making and breaking contact with its wires, sparks half an inch long and of dazzling brightness passed with a report like the discharge of a large Leyden battery. It ignited 3 feet of iron wire $\frac{1}{10}$th of an inch in diameter, and fused into a boiling liquid two inches of a thick rat-tailed file.

To complete the evidence of the effect of heat on the battery, the converse of the preceding experiments was tried.

Influence of cold.—Eight cells of the same dimensions as those used in the former experiments were arranged with new zincs, fresh solutions, and new leathers, under circumstances in short, all calculated to promote galvanic action. The decomposing power of this battery in air and water at 84° was found to be equal to 40 inches of the mixed gases in three minutes. The temperature was then gradually lowered by the addition of ice to the water surrounding the battery, when the following effects were observed :

Temperature.		Power of battery.		Time.
84	....	40	....	3 minutes.
79	....	38	....	3
73	....	35	....	3
69	....	32	....	3
65	....	30	....	3
62	....	30	....	3
60	....	28	....	3

The battery when cooled to 60° had been at work two hours. The cold water was then drawn off and without disturbing the battery this was allowed to regain the standard atmospheric temperature, which it acquired in one hour and forty minutes. Its power was then tried and found to be 39 inches of gas, being within one inch of the quantity it produced at the same temperature at the commencement of the experiment four hours before.

It is a curious circumstance, that the liquid in the decomposing cell is not similarly influenced by changes of temperature. A pair of platinum poles were introduced into a retort half filled with acidulated water. A battery being connected with these plates, evolved six inches of gas in three minutes at 90° Fahr. The liquid was then raised to the boiling point, and still six inches were the product. Allowed to cool and then introduced into a

freezing mixture till brought to 40°, the same quantity was still obtained.

These experiments have since been repeated and verified by Professor Daniell, of London.

It is however a very extraordinary fact that increase of temperature does not produce the same effect on the gold battery. It seems that in this the affinities in play have at common temperatures reached their highest activity.

It should be mentioned here that the approach of storms especially from the northwest has a strong but unexplained power of increasing the decomposing force of the battery. The increase has been as much as one-third in several experiments I made in 1839.

Diminishing the pressure of the atmosphere on the surface of the battery cells retards rather than promotes their energy.

The decomposing bottle, plates and liquid may be placed in vacuô, or subjected to increased pressure to the extent of three atmospheres, without the least difference occurring in the amount of the decomposition.

We have now a sufficient idea of the nature of the chemical force of the battery and of the mode in which it is best directed. We have found too that a few plates are proportionately more powerful than a numerous series. We have next to attend to the powers of the decomposing plates when other substances than water are under their action.

There are in nature fifty-five elementary bodies, of which four are gases or airs, twelve non-metallic solids or fluids, and the rest metals. Of these it has been proved that oxygen, chlorine, fluorine, iodine, and bromine always during decomposition appear at the plate which

corresponds to the positive side of the battery, while hydrogen, and the metals are evolved at the side corresponding to the negative pole of the arrangement. The relations of phosphorus, carbon, nitrogen and sulphur are less understood. When saline bodies are decomposed the acid goes to the zinc, the alkali or oxide to the copper side. This constancy of attraction led Sir H. Davy and others to investigate the electric nature of the extremities or poles of large galvanic series, and it was found that the copper end gave unequivocal proof of vitreous (positive), the zinc end of resinous (negative) excitement. Now as dissimilar electric bodies attract, and similar repel each other he termed oxygen, the acids and those bodies of that class "Electro-negative," as they were attracted by the positive pole—and hydrogen, the alkalis, oxides and metals he called "Electro-positive" as these were attracted by the negative pole*.

The terminations of wires connected with the extremities, and which were formerly called "Poles," Mr. Faraday terms "*Electrodes*," or the paths for the electrical discharge. The positive pole he names the *anode* or entering path, and the negative he calls the *cathode* or descending or departing path. The fluid under decomposition he names the *Electrolyte*.

In effecting chemical decomposition (electrolysis) there are certain conditions of the electrolyte without which its elements (*ions* as Faraday terms them) cannot be separated.

* *Within* the battery the zinc is positive, the gold, platinum, or copper, negative. Thus the zinc is oxidized and the hydrogen goes to the opposite metal. But when a series of plates are arranged and connected with poles *outside* the battery, the pole belonging to the zinc end is *negative*, and on this hydrogen, the alkalis and metals are obtained; while the pole of the gold, copper or platinum side is positive and yields oxygen, chlorine, iodine and the acids.

First. The compound must be either in solution or fusion. For instance water if frozen not only resists decomposition but completely prevents all circulation of the electric force.

Secondly. The electrolyte must be a conductor of galvanic electricy. Thus turpentine and the liquid resins, which are non-conductors, are not decomposable by any number of cells. Water in the pure state conducts but feebly and is very difficult of decomposition, but on adding a little sulphuric acid its conducting power being increased, it is decomposed with proportionate facility.

Thirdly. It is established by Faraday's experiments that it is only those compounds which consist of one atom of each of their constituents, viz: protoxides, proto-chlorides, proto-iodides, &c. which undergo *direct* decomposition. But there are again many such compounds which cannot be electrolyzed.

Fourthly. The electrolytic power of a battery of any given size depends on the power of each cell in the series, and if a cell from any cause fails in its action the whole force of the entire series falls to the same degree. Thus if in a battery of 12 plates 144 superficial inches each, the decomposing power being equal to thirty inches of gas in three minutes, if for one of the plates we substitute one of seventy-two inches' surface, the decomposing power of the whole twelve falls at once to fifteen inches of gas in three minutes.

Fifthly. In decomposing a compound it is essential for the transfer of its constituents to either electrode that each element shall find another to combine with it chemically along the whole line between the electrodes. Thus if we place the positive electrode in a solution of sulphate

of magnesia and pour distilled water carefully over this, and into the distilled water place the negative electrode, the sulphate of magnesia will be decomposed, its acid be evolved at the positive electrode, but the magnesia be deposited in the solid state at the line of contact between the saline solution and the distilled water. Magnesia being insoluble in water cannot find its way through that fluid to the negative metallic electrode.

It is necessary too to distinguish between the effects of *direct* and *secondary* decomposition.

By *direct* decomposition is meant the evolution of each element of a compound in the state in which it first entered into combination. Thus binary compounds, such as water, chloride of lead, &c. give up their elements at either electrode. But when compound bodies or mixtures of various electrolytes are used, the elements of these frequently react on each other, and new and often unexpected forms of matter present themselves at the electrode.

Thus when a solution of sulphate of oxide of copper in water is decomposed, we find the water and the salt are simultaneously electrolyzed. The acid of the salt and oxygen of the water are evolved at the positive or anelectrode, and we might expect the hydrogen of the water and the metallic oxide to appear together at the cathelectrode. Such however is not the case. The oxide of copper and hydrogen at this electrode react upon each other by ordinary affinity, the hydrogen and oxygen unite and form water, and the metal is deposited in the pure state.

All the metals which are incapable of decomposing water under ordinary circumstances, may be thus obtained from solutions of their salts. Gold, silver, cop-

per, tin, lead, iron and platinum are thus procurable and usually in a highly crystalline state.

The metals which decompose water at common temperatures, for example potassium and sodium, cannot be obtained from the watery solutions of their salts.

If the electrode be of a metal which can combine directly with the substance evolved upon it in electrolysis additional phenomena of interest occur.

Thus if gold or platinum be made positive in a solution of common salt (chloride of sodium) the chlorine combines with the gold or platinum which is corroded and dissolved. If silver be positive in this solution the white chloride of silver is formed on the surface of the plate.

As platinum and gold are not corroded by ordinary acids or alkalis, these metals are preferred in the electrolysis of all compounds not containing chlorine. The ordinary metals, copper, tin, iron, lead, zinc, &c., all become oxidized and dissolved at the positive electrode when watery solutions of oxygenized salts are decomposed. Some very beautiful experiments may be performed by making various metals positive in neutral solutions of saltpetre (nitrate of potash) and mixing with this solution a few drops of the tests of the different metals.

Expt. 1. Place an iron wire in a solution of saltpetre mixed with a little tincture of galls. The liquid in contact with the iron is rapidly converted into *ink* on the battery circuit being completed, the arrangement is shewn in plate 3, *fig.* 4. The iron should be positive.

Expt. 2. Use similar solutions and apparatus, but for tincture of galls substitute a little of the yellow salt called

prussiate of potash. Apply the battery and Prussian blue is immediately formed round the iron electrode.

Expt. 3. Mix a solution of starch with one of ioduret of potassium, a colorless transparent salt. Use platinum electrodes and the same apparatus as above. Iodine is set free at the anelectrode and acting on the starch gives it a fine blue colour.

Expt. 4. Use the solutions of the first experiment and a leaden anelectrode; add a few drops of chromate of potash or ioduret of potassium dissolved in water; the yellow ioduret or chromate of lead is formed when the battery is applied.

Expt. 5. Use a solution of common salt (chloride of sodium) tinged blue by indigo previously dissolved in sulphuric acid; let the electrodes be platinum. Apply the battery and the instant liberation of chlorine at the anelectrode bleaches the indigo solution.

The common operation of chemical affinity may in many instances be resisted or turned aside by electric forces. Sir Humphrey Davy's memorable attempt to protect the copper sheathing of ships from corrosion by sea-water affords a good illustration of this kind of interference with ordinary affinity. The copper is corroded chiefly by the chlorine of the sea salt. Sir Humphrey Davy found that by attaching small pieces of zinc or iron to the copper the latter was completely protected by being thrown into the negative electric state, while the chlorine and oxygen of the sea water were evolved on and corroded the zinc or iron protector.

Silver or copper may thus be introduced into strong nitric acid and no solution of the metals occurs, so long as by the association of a more positive electrode these are kept in the negative state.

It has been lately found by Becquerel, Cross, Fox, Bird and others, that by the long continued use of low galvanic powers several very interesting compounds may be formed, which no other process will afford. Of these many are identical with natural minerals and gems. They are formed by the slow action of very weak batteries on solutions containing silica or flint and various earthy or metallic bases; minute crystals of different silicates are thus gradually formed about the positive electrode. The crystals are usually microscopically small, and thus the experiments lead to no hope of our being enabled by this method to manufacture gems, the possibility of which is now a matter of popular belief.

I shall conclude this notice of the chemical powers of the battery by a few hints to those slightly acquainted with practical chemistry, on the extemporaneous preparation of some useful and interesting substances by this apparatus.

Expt. 1. Procure a porous earthen-ware bottle, (air-tight,) introduce a platinum or gold plate, and fill the bottle with dilute sulphuric acid. Let the platinum plate have a wire or strap protruding through the cork which is perforated and provided with a bent tube for delivering gases. Place the arrangement in a tumbler containing dilute acid. Apply a battery of twelve cells, and let the inner plate be in connexion with the gold or copper side. Oxygen gas is given off freely in a state of perfect purity.

Expt. 2. Reverse the battery wires, so as to connect the inner plate with the zinc side. Hydrogen gas is now obtained.

Expt. 3. In a similar apparatus use a strong solution of oxalic acid, a compound of two equivalents of carbon and three of oxygen. Make the inner cell positive and carbonic acid (carbon one equivalent, oxygen, eq. two) is liberated. If the inner cell be negative carbonic oxide is obtained.

To obtain chlorine charge the inner cell with muriatic acid and use a platinum electrode, make this positive and chlorine is abundantly set free and may be collected over warm or salt water.

In concluding this notice of the chemical powers of the galvanic battery, I may observe that the chief object to be gained in this department is its application to the cheap supply of oxygen and hydrogen gases by the decomposition of water. Within the last year the experiments of Grove and those I have myself carried on, have made much progress towards the accomplishmeut of this object. If this be once effected we have at our disposal the most powerful of all agents for producing concentrated heat, and a forçe applicable to machinery far superior to steam in any of the present modes of employing that mover. The heat and expanded vapor suddenly produced by exploding twenty-eight cubic inches of oxygen and hydrogen (obtained by decomposing three grains of water) is sufficient to propel a 12lb. shot to a vertical height of twenty-three feet in less than one second of time. By the simplest machinery this immense power is made to act without any audible explosion; in its nature it is moreover so manageable that it can be directed with the most complete safety and ease.

LECTURE FOURTH.

ON THE MAGNETIC EFFECTS OF THE GALVANIC BATTERY.

The leading properties of the loadstone and of steel magnets are now familiar to all educated persons. The most remarkable are the tendency of the magnet to place itself north and south, to attract pieces of common iron brought into its vicinity, to communicate its own properties to similar pieces of steel by the operation of friction or contact—to attract the dissimilar pole and to repel the similar pole of other magnets.

It was long supposed that electricity in some disguised and inexplicable state was connected with these phenomena. Flashes of lightning and discharges from the Leyden battery were known to excite magnetism in steel, sometimes to destroy, sometimes to reverse the polarity of magnets. In 1820 it was that Oersted, the Professor of chemistry at Copenhagen, made the great discovery of the influence of galvanic electricity on the magnetic needle.

In plate 2, *fig*. 3, are represented a pair of galvanic plates, zinc and platinum with a conducting wire led from one to the other in a rectangular course. Within this rectangle a magnetized needle is suspended by a silk thread. Let the rectangle point N. and S. and the wire be divided at *p*; the magnetic needle of course points N. and S. also, or is in the same vertical plane with the rectangle itself. The zinc plate corresponds to the end of the wire, which would be south were the wire extended in a straight line. Let the divided ends of the wire be reunited and the needle is instantly deflected and places itself at right angles to the coil. The deflected needle now points to the *east*.

Were the needle suspended above instead of below the conductor the deflection would be to the *west.*

If the attachments of the wires to the galvanic plates be changed, so that that which was united to *z* shall be joined to *p* and vice versa, the needle is deflected in the contrary direction to that taken in the two previous experiments.

If the coil of wire instead of running above and below the needle surround it in the same horizontal plane, the needle will move vertically, and its northern end be elevated or depressed according to the order in which the ends of the rectangle are attached to the galvanic plates.

If in these experiments fixed magnets and moveable rectangles of wire be employed, the wires will move in the opposite directions to those which would be taken by the needle.

If a copper cup, see plate 2, *fig.* 4, have a small zinc plate placed within it suspended by a stout copper wire from the cup, and this galvanic cell be charged by weak acid, on placing the cup on the surface of water so that it floats freely, it will turn round gradually and so place itself that the edges of the wire will point E. and W., its surfaces N. and South.

If to the surface which faces the north we approach the pole of a steel magnet the coil is immediately repelled. The south pole of the steel magnet attracts it as forcibly. The reverse effects are produced at the opposite side of the coil.

(This arrangement is called De la Rive's floating magnet.)

If the conducting wire be covered with silk and twisted into a close spiral, half an inch in diameter, and

three or four inches long, on introducing a common needle and then applying a galvanic couple the needle is by a single contact converted into a permanent magnet with N. and S. poles. If without withdrawing the needle, the connexion of the wires be reversed, the polarity of the needle is destroyed on the battery contact being made.

If this spiral be made the conductor between the extreme plates of eight or ten powerful cells, such as those of Mullins' batteries or of the gold arrangement, it will be found to attract towards it large masses of iron filings, which instantly fall off on contact with the battery being broken.

From all these facts it is manifest that the conducting wire of a galvanic series is a magnet while in connexion with the battery, but that its magnetism ceases when contact with the battery is broken.

As the theory of these effects would lead me into a discussion foreign to the objects of this lecture, I reserve it for the series in which electro-magnetism is separately considered.

We have seen above that the conducting wire is magnetic. In virtue of that property it is that it induced permanent magnetism in bars of steel submitted to its influence. If instead of a steel needle we employ a soft iron wire in the experiment illustrated in plate 2, *fig.* 5, we find the soft iron powerfully magnetic, while battery contact is mantained, but that it instantaneously returns to its original state on the contact being broken. And if in the first position of the conducting wire one of the ends be *north*, on changing or reversing the connexions of the ends of the wire the north pole of the temporary magnet assumes a south polarity.

The diagrams in plate 4, *figs.* 3 and 4, illustrate more plainly the experiment of changing the poles of a temporary iron magnet without disturbing its position.

Various ingenious contrivances have been made for effecting this reversal of the polarity of temporary magnets by a single mechanical movement. The figures 5 to 7 in plate 4, shew one of which I published a description in 1837, and which I have since adapted to several forms of electro-magnetic apparatus.

Four thick copper wires are sunk in a board a foot square at one inch distance from each other, and each bent at a right angle in the manner shewn in *figs.* 3, 4. At the ends and angle of each wire is inserted a glass tube two inches high, open at both ends, and in which is placed about an inch of mercury which must be well in contact with the wire. It it obvious that by inserting a wire from *a* to *b* and *a′* to *b′*, the electric influence will pass in a direct course from *x* *x′*, to which the battery poles are connected to *m* *m′*, where the ends of any conductor under experiment are to be attached. Two bent wires are accordingly placed at the end of a lever *fig.* 6—so that they may be simultaneously made to rise from or fall into the mercury by acting on the end of the lever *a*. Two cross wires, see *fig.* 7 carefully insulated from each other, move in the angle tubes, being fixed to a square slip of wood so that when this descends it presses on the levers, lifts their wires from the mercury and a diagonal instead of a direct course is established for the electric current as in *fig.* 4*.

When considerable masses of soft iron are bent into the horse shoe shape and carefully surrounded with silk.

* The whole is shewn in action in *fig.* 5.

ed copper wire $\frac{1}{10}$th of an inch in diameter, the wire being lightly and firmly wound round the iron in a close spiral, and as nearly as possible at right angles to the axis of the bar, on connecting the ends of the wires with a galvanic battery of Mullins', Grove's, or my own construction, the iron becomes a magnet of enormous power.

The principle of the arrangement is shewn in plate 2, *fig*. 6. The experiment represents a temporary iron magnet belonging to the Medical, College. It weighs but four ounces, but when attached to a battery of six of the gold cells it sustains thirty-five pounds weight suspended from a little bar of soft iron applied to its poles.

Another temporary magnet in the College museum, formed of two inch round iron, bent into a horse shoe, the legs three inches apart and six inches long—the whole weighing twelve pounds, and surrounded by forty yards of thick insulated wire, supports, when excited by twelve gold cylinders, the immense weight of over five hundred pounds. Plate 4, *fig*. 8.

The College also possesses a magnet of three inch soft iron, the legs of which are each six feet long and one foot apart. It is surrounded by four thousand feet of thick insulated wire wound at right angles to its axis from one end to the other. At each two hundred and fifty feet of wire this is cut, and the ends turned out to admit of different parts of the bar being galvanized for experiment, or to allow the wire to be used as one entire length or in several shorter circuits. On connecting this spiral with a battery of thirty of the copper cells shewn in plate 1, *fig*. 8, the bar became so powerful a magnet that it readily supported 2,700 lbs. suspended from its poles. At six inches distance it was impossible for the

hand to resist its attracting force on a piece of iron two lbs. weight, which was drawn up with a violent stroke like the blow of a powerful hammer.

These temporary magnets retain a great portion of their power so long as an iron bar (or armature) is allowed to connect their poles. But the instant this is removed all magnetism is destroyed. The twelve pounds' magnet above described, see plate 4, *fig.* 8, after a single contact with a twelve cell gold battery retains its armature *b* with a force of eighty-seven pounds. But when the armature has been detached the iron is incapable of attracting or supporting the smallest particle of iron filings.

We have now seen proof of the magnetism of the galvanic conductors, and of the power these possess of causing steel and iron to assume magnetic properties also. We shall next find that conductors have likewise the power of causing adjacent wires, totally unconnected with them or with the battery to assume an electric state.

Let *a, b,* be the conductor from an active battery *c,* and let *d, e,* be an endless wire parallel to but not in any way touching or connected with *a, b.* So long as *a, b,* are in contact with the battery no effect is perceivable in *d, e,* but at the moment contact is made, or at the moment it is broken, between *a, b,* and the battery, the adjacent wire *d, e,* is in a state of transient but powerful electric excitement. Plate 5, *fig.* 1.

The contact may be made or broken in any part of the primary circuit *a, b.*

The proof of the electric excitement of *d, e,* is obtained by placing in any part of its circuit a delicate magnetic needle pointing N. and S., in which direction the wire

under experiment should be placed. On making or breaking contact in *a, b,* the needle is deflected and points east or west.

Instead of the coil and needle two fine platinum points placed in a glass containing water acidulated with sulphuric acid may be employed, see plate 5, *fig.* 2. On making or breaking battery contact the water is decomposed and minute bubbles of gas are set free.

Or if a pair of brass handles be attached to the divided wire and grasped one in each hand, on making or break-battery contact a shock is experienced.

Or if by an appropriate mechanical contrivance contact in both the circuits is broken at the same moment, a spark is seen to pass at the interruption in the secondary wire.

It is a most remarkable and extraordinary fact that the effects on the living system produced by the electricity of the secondary wire far surpass those of the primary one. The reader will remember too that it is no portion of the galvanic electricity which is abstracted from the primary conductor, but it is the vicinity of this which disturbs the latent electric matter in the secondary wire. It is the inherent electricity of this which shews itself in these conspicuous phenomena.

An electric machine of extreme energy has recently been constructed on these principles. It is so cheap, simple and portable, and so applicable to manifold purposes of the greatest interest, that I shall describe its construction so minutely as to enable the reader to have it manufactured for himself.

One hundred yards of silked copper wire ($\frac{1}{16}$th of an inch in diameter) are wound round a wooden bobbin, in a close spiral from left to right and back again with-

out crossing, for any number of tiers it may form. The ends protrude a few inches and are cleared of their silk to permit their being connected with the battery. This connexion is best made by brass binding screws, such as that shewn in plate 5, *fig*. 3.

Around the primary coil and in the same direction are wound from 500 to 750 yards of the very finest and thinnest copper wire which can be made, carefully insulated with silk and all in one continuous strand. The ends project as in the first coil, and by means of binding screws may be attached to a galvanometer, to chemical decomposing plates, or to handles for communicating shocks. Plate 2, *figs*. 7 and 8.

For making or breaking contact with the battery various simple contrivances may be had recourse to. Thus in any part of the primary coil insert a ratchet wheel of brass with a metal click; connect one of the ends of the divided wire *p* with the wheel, and the other end *z* with the click. Let the ratchet be made to revolve by a spindle and multiplying wheel *d*. At every time the click passes a notch on the ratchet contact is broken and then restored, so that this effect may be produced several times in a second. See plate 5, *figs*. 4, 5.

All the effects produced by the secondary coil are multiplied at lest ten-fold by inserting in the axis of the bobbin a bundle of soft iron wires covered with silk and cut into lengths of about eight inches each. Plate 2, *fig*. 8.

The Medical College possesses an instrument of this kind. The coil weighs two pounds, is five inches long and three broad. The bundle of wires weighs six ounces. When the primary coil is connected with one gold or two copper cells, the shocks given on turning the wheel are altogether intolerable. Their severity may be reduced

at pleasure to a mere feeling of pulsation in the hands by withdrawing the bundle of iron wires or by reducing the number and force of the galvanic cells. The machine costs but five pounds, and an excellent one may be made in India for half that sum.

This instrument is in daily use in the College Hospital for giving shocks in cases of paralysis, rheumatism, &c. Its applicability for communicating telegraphic signals is fully explained in a succeeding lecture.

Besides the effects above described, it is desirable to notice some other phenomena which present themselves or may be produced at pleasure in galvanic experiments with large batteries.

Owing to the magnetism developed in the conducting wires, if long or slender wires be employed in any part of the circuit, strange vibrating motions are seen to agitate these whenever contact is made or broken with the battery. The rigid wires of the great cistern battery were so powerfully affected as to be drawn violently together through the whole length of the battery. The wires were about four inches apart from each other.

A very beautiful experiment may be performed by making a large and heavy close spiral of thick copper wire and suspending it by one end from a metallic rod. Its own weight opens out the spiral. Let the other end just dip on the surface of mercury in a glass tube, the mercury being connected with one pole *p* of a powerful battery. Apply the other pole *z* to the supporting rod and the spiral will be instantly seen to leave the mercury with a convulsive start. It descends immediately, touches the mercury and contracts again. This convulsive starting is kept up regularly so long as the battery

continues in action, and a beautifully bright spark is seen on the surface of the mercury whenever the point of the wire quits it. This effect depends on the turns of the wire being magnetic while in the galvanic circuit, and being mutually attractive of each other. When the circuit is broken the magnetism ceases and the spiral lengthens by its own weight—see plate 5, *fig.* 6.

The magnetism of the conducting wire is very beautifully shewn by Faraday's celebrated experiment of causing magnets and conducting wires reciprocally to revolve round each other. These experiments will be described minutely in another series of lectures.

When very large batteries of numerous cells are arranged in uninterrupted order from the first to the last of the series, it has been mentioned in a preceding lecture that a brilliant band of flame will pass uninterruptedly from the poles, if having been joined these are slowly separated to a moderate distance: this band of flame is highly magnetic. If the conductors be vertical the flame bends itself east and west, or at right angles to the magnetic meridian. If a powerful steel magnet be made one of the poles the flame revolves around it, but at the same time the magnet melts into incandescent globules.

THE GALVANOMETER.

This most valuable instrument was invented by Schweigger soon after the announcement of Oersted's great discovery.

Schweigger found that the deflecting power of the conducting wire was greatly increased by insulating this with silk and causing it to run in repeated turns round the needle. The more massive the wire, within

certain limits, the smaller will be the force required to deflect the needle. The delicacy of the instrument is increased to an extraordinary degree, by taking two magnetized needles of equal power, suspending one above, the other beneath the coil at about $\frac{3}{4}$ of an inch apart, and with their dissimilar poles in the same direction; the needles are joined by a straw or a little ivory stem and suspended by a single fibre of unspun silk; Plate 5, *fig.* 7.

By this arrangement the influence of the earth's magnetism on each single needle is neutralized and the deflecting effect of the upper surface of the coil is brought into operation.

This form of the instrument is called the *astatic* galvanometer. It is of such exceeding delicacy that when properly constructed it measures degrees of current electricity almost inconceivably minute.

The deflection of the needle is measured on a graduated card, and the force of the deflection ascertained by the number of turns it is requisite to twist the supporting thread through to overcome the deflection and bring back the needle to zero. From this mode of measuring the force the instrument is often called the Torsion or twisting Galvanometer.

The delicacy of this instrument is such that the electric action caused by a drop of water falling on a plate of copper and touched by a zinc pin is instantly shewn by a considerable deflection. It has detected electrical movements in the atmosphere, in plants and in living animals under circumstances when no other instrument would have succeeded. It may indeed justly be regarded as the microscope of electricity, and although it has disappointed many who attempted by its means to unravel

the laws of large and powerful galvanic combinations, it still has thrown much light on operations which but for its assistance would have remained for ever obscure.

The purposes of practical utility to which the galvanometer has been applied are equally numerous and interesting. It is the indicating agent in Wheatstone's telegraph now in operation between London and Bristol, and in Melloni's hands it has been made a thermometer of such exquisite delicacy that it reveals and measures the vital heat of an insect or a flower.

Before closing this lecture I wish to offer a few remarks on the application of the magnetic forces developed in soft iron by the galvanic battery, to the movement of machinery for practically useful purposes.

On witnessing for the first time the experiment of several hundred pounds suspended from a small iron bar by the simple force of attraction, and on observing the inconceivable rapidity with which this force is annihilated, it is impossible not to speculate on its applicability as a motive power.

One of the earliest attempts bearing the appearance of success towards accomplishing this object was that of which I published an account in the Journal of the Medical Society of Calcutta for January, 1837. I there shewed how masses of iron disposed in a wheel weighing 18 lbs. could be kept in rapid revolution by the action of a single galvanic couple. Mr. Davenport, in America, about the same period constructed an analogous machine.

Since then Jacobi, of St. Petersburgh, and several other experimentalists have followed up the subject. The practical results have been the working of a small

printing press, of a turning lathe and drilling machine, and the propulsion of a small boat having on board two persons at the rate of three miles an hour in still water.

For the information of those who may desire to try experiments on this subject, I should state that *hollow* iron magnets (made from gun-barrels for instance) are equal in power to those of solid metal. Soft iron wire covered with silk or varnish and cut into lengths is superior in magnetic susceptibility to both.

To persons of mechanical turn there can be no difficulty in constructing, on the principles I have explained, a great variety of machines impelled by this agent. I believe these will be found valuable and effective in many processes where a constant force less than that of a man is required; but on the other hand I now feel convinced from all my experiments on this subject that for any thing beyond this, high pressure steam will be found a cheaper and more efficient agent; and that the machinery for this form of steam need not be more ponderous than that of an electro-magnetic engine of equal power. The great obstacle to the use of the latter force is inherent in its nature and cannot be counteracted. I mean the shortness of the distance through which electro-magnetic attraction operates. A magnet which supports a ton may be unable to attract an iron wire from six inches distance. On another occasion I shall have to return to this subject and enter for illustration's sake on the working details of one or two of the most promising of these engines which have been brought forward.

LECTURE FIFTH.

ON THE GALVANIC SPARK—THE DEFLAGRATION AND IGNITION OF METALS—AND THE EXPLOSION OF MINES UNDER WATER.

When the conducting wire of a small galvanic couple, plate 2, *fig.* 3, is divided, or contact otherwise broken in its course, a faint spark is discernible at the point of separation. This spark is best seen by dipping one pole under the surface of clean mercury in a glass and making and breaking contact with the other pole from the surface of the liquid.

By increasing the size of the galvanic pair the spark becomes proportionately vivid.

If the conducting wire be lengthened it is found that within the limits of 300 or 400 feet, the longer the wire the more brilliant is the spark, so that what was scarcely perceptible with the short conductor is bright and large when the long wire is employed.

The spark from a single pair of plates is remarkably increased by winding the conductor (silk-covered) into a close spiral; still more so if a bar of soft iron be placed within the spiral.

If the conductor be formed of a copper strap one inch wide, 200 feet long, covered with tape for insulation and rolled in a spiral coil, the spark on breaking contact is of the most intense brilliancy, and accompanied by a snapping report. This coil is named after its inventor Professor Henry, and is shewn in plate 5, *fig.* 8. One end of the coil is attached to the first plate of the couple; the second end *b* dips beneath mercury in the

glass *c*. From the other plate of the battery a conducting wire is brought so as to touch or leave the mercury at the experimentalist's pleasure.

When ten couples of plates are employed (without the coil) the spark increases much in size and brightness, but when the coil is interposed its volume and splendour are so augmented that a continuous light of dazzling brilliancy is obtained by a series of rapid separations of the wire from the mercury.

This however undergoes combustion very rapidly and the fumes obscure the effect and are deleterious to persons in the vicinity.

Increasing the numbers of the galvanic series produces corresponding increase of the spark till at length deflagration or the rapid fusion and dispersion of the end of the wire occurs.

With the gold battery and copper wire conductors $\frac{1}{8}$th of an inch thick, the spark passes into deflagration about the tenth couple: twenty-five couples may be said to explode the termination of the wire. This melts into large globules which suddenly burst and scatter showers of white hot drops in every direction. With forty-eight gold cells the experiment is one of some little danger from the intense heat, abundance and velocity of the drops of molten metal. An arrangement for repeating this experiment is shewn in plate 3, *fig*. 6. Only a few plates of a skeleton battery are shewn.

It is a singular and unaccountable circumstance that the deflagration is much greater when the wire of the gold end than when that of the zinc end of the battery is employed. If instead of mercury we use a large piece of box-wood or ebony charcoal connected with one pole, and break contact with the other, the metal is similarly

acted on, and the charcoal ignites and sheds a light of inconceivable brilliancy.

Every metal is fused and dispersed in this manner. Each burns with a different colour. Gold gives a white light tinged with blue, silver emerald green, copper bluish white with red sparks, lead purple, zinc a brilliant white and red with copious white clouds. But the most superb effect is when thick steel springs, scizzars, files, penknives, or daggers are employed. A round file half an inch in diameter and twelve inches long was in one of my experiments melted down in less than a minute, scattering cascades of fiery stars of indescribable beauty in every direction. These stars though at a white heat fall on the hands and hair without burning them, like the scintillations from a grindstone or the sparks from a smith's anvil.

If instead of repeatedly breaking and renewing contact the poles be gently separated, the arch of flame described in last lecture, page 59, plays between the conductors. This arch requires for its production a numerous series of active cells. With 400 of Mullins' cylinders it was one and a half inches long and quite constant in its flow.

The temperature of this arch is higher than that of any other source of heat with which we are acquainted. Platinum melts in it like wax, and the most infusible minerals are liquified or dissipated. Its magnetic properties have already been described in the last lecture.

Reserving the peculiar and important phenomena connected with the ignition of charcoal for explanation and comment in another lecture, I proceed to the subject of the *ignition* of metals.

It has been already stated that metals differ in their

degree of conducting power for the electric current. Now it is found that as this circulates through wires it increases their temperature in the inverse ratio to their conducting power, the best conductor being (for equal length and size of wire) the least heated.

The cistern battery belonging to the Medical College had its poles connected by a platinum wire thirteen feet long and $\frac{1}{20}$th of an inch in diameter: the whole length of the wire became white hot. Eleven feet were instantaneously melted into thousands of drops like small shot.

The same length of iron wire was similarly affected, seven feet of copper wire ($\frac{1}{20}$ inch) were melted, and three feet of copper wire ($\frac{1}{10}$) kept at a white heat. Pieces of platinum foil an inch broad and twelve long were fused by a single contact.

The best galvanic arrangement for producing these effects is that of about twelve pairs of plates of large surface. To *deflagrate,* a battery requires a long series of cells, but to *ignite,* a few large cells are necessary. Numerous small cells however may be so connected as explained in page 37, as to be equivalent to a smaller series of larger surface.

Thus in the forty-eight cell battery all the golds of eight cells may be connected by a common wire or strap. The zincs are similarly arranged. A set of eight cells thus constitutes one couple of eight times the surface of each single cell. The battery gives six such sets. The zincs of number one are connected to the golds of number two, and so on. This is called the *quantity* order. The gold battery thus arranged surpasses in igniting effect the thirty-six feet copper cisterns before described*.

* Another method of making the quantity arrangement of a battery of forty-eight cells is by connecting each set of eight in the ordinary manner so as to form six separate sets. Then let all the

The most important purpose to which these facts have been applied is to the explosion of gunpowder under water for the destruction of sunken wrecks, rocks and the like obstructions to navigation. Dr. Hare of Philadelphia was the first to propose this method. Colonel Pasley, the distinguished Engineer of Chatham, has the merit of establishing the practicability of Hare's suggestion and of being the first to destroy in this manner the wreck of a vessel sunk in the river Thames. In December, 1839, I had the pleasure of superintending the galvanic arrangements for the explosion of the wreck of the " Equitable" in Fultah Reach, in the Hoogly. As the experiments I undertook on that occasion exhibit completely all the practical points to be attended to in these operations I shall occupy this lecture by describing them in some detail.

DESTRUCTION OF THE WRECK OF THE "EQUITABLE" BY GUNPOWDER EXPLODED BY THE GALVANIC BATTERY.

The galvanic battery employed consisted of twelve of the rectangular cells described at page 24.

The object of the experiments was to cause a piece of metallic platinum or iron to become red hot while inserted in the gunpowder in a cylinder mine to be sunk in contact with the wreck in 36 feet of water at the lowest time of the tide. As iron rusts very speedily platinum was of course preferred.

The whole of the circumstances likely to influence the ignition were first carefully studied.

It was found that at 130 feet distance from the battery the conducting wires being of copper $\frac{1}{12}$th of an inch in

gold poles be united to a common strap—and all the zincs similarly connected. These straps constitute the poles or electrodes ; this order equals in " quantity" effect that above described.

diameter, two inches of stout platinum wire were heated sufficiently to set saltpetre match-paper on fire.

With two strands of the same wire the same effect was produced at exactly double the distance. With three strands the distance was rather more than trebled.

With a weaker battery this increase of the wire was carried to six strands with the result that so far as our experiment extended to the igniting distance increased arithmetically in proportion to the mass of the conductor. It was observed in these experiments that supposing *two* inches of platinum wire were ignited at 130 feet, shortening the platinum instead of increasing its heat had exactly the contrary effect, and that when reduced to half an inch the platinum was scarcely perceptibly warm.

Interrupting the course of the circuit in any place at once of course causes the platinum to become cold; or if metallic communication be made between the wires between the battery and the platinum, the electric influence does not proceed beyond the first metallic contact and the platinum is not ignited.

If the conducting wires are led through water, without any insulation, the igniting distance is shortened to one-third, the wires being three inches apart from each other.

These facts induced me in the explosion of the "Equitable" to employ three-strand wires kept three inches apart by pieces of wood in the form of the ladder shewn in plate 6, *fig.* 1.

Approximation of the wires nearer than three inches rapidly shortens the igniting distance. But on the other hand separating the wires beyond three inches does not materially lengthen the distance of firing heat. I found however that by floating one of the wires by running it

through a series of corks, secured by pitch (plate 6, *fig*. 2,) and lashing the second wire outside the cork the igniting distance was the same as when the dry conductors were employed. The corks for 480 feet of conducting wire cost but sixteen rupees; the conductor floated freely, was flexible, light and manageable in every direction.

The next object was to secure the loop of platinum wire from mechanical strains which would endanger its breaking; and at the same time to protect the powder with which it was to be placed in contact from the access of water or even of moist air.

My apparatus was thus prepared: see plate 6, *fig*. 3,—fifteen inches of the thick end of a gun-barrel *g*, *g*, were cut off, and a male screw turned on the barrel near its centre. To this screw was fitted a square plate of iron, half an inch thick by about five inches square *i*, *i*, having a hole at each angle to admit of fastening screws being inserted. A teak rod *t*, *t*, eighteen inches long, was now prepared so that it would just enter the gun-barrel when nearly red-hot; two grooves were cut in the opposite sides of this rod, and the conducting wires let into the grooves and securely fastened in with a strip of wood and pitch cement. The rod and wires were then driven into the hot gun-barrel, and the whole immediately plunged in cold water. The contraction which ensued bound the rod and wires so firmly that no force could possibly affect the platinum loop, nor any leakage occur through the iron tube.

An inch and a half of platinum wire (*p*) was next soldered to the end of the conductors, and over these was tied a paper cartridge containing mealed Dartford powder; the cartridge was protected by a copper tube *G*, which screwed on to the end of the gun-barrel, and

projected about three inches beyond the platinum loop. This tube was filled with Dartford powder and securely closed by a wooden stopper, cemented into its place by melted pitch.

The ignition of the platinum wire would explode the cartridge, and this the surrounding Dartford powder, which must burst the tube and explode the contents of the mine in which it was placed.

The mine for the destruction of the "Equitable" consisted of a barrel-shaped wooden vessel, about seven feet long by three and a half feet in diameter, capable of containing 2,500 lbs. of powder. The square iron plate *i, i,* plate 6, *fig.* 3, was screwed into the side of this vessel, which was subsequently enclosed in thick sheet-lead. Into the iron plate the priming tube, above described, was firmly screwed, a washer of lead being placed in the joint.

Besides the arrangements above described it became necessary to contrive some self-acting apparatus, to complete the battery circuit or to direct it through the platinum wire at any given time. This was rendered essential by the decision of Captain Fitzgerald the Engineer Officer employed to direct the operations, that the galvanic battery should be placed immediately over the mine. The means by which this was accomplished I have described in a paper published on this subject in the Journal of the Asiatic Society, and of which the following is a sufficient analysis:

Bearing in mind that all that is required to prevent the ignition of the platinum wire is to cut, or otherwise interrupt, one of the conductors—or else to bring the wires into metallic contact with each other between the battery and the platinum loop—it will be easy to under-

stand the action of the two pieces of apparatus which I now proceed to describe, quoting from my paper already referred to.

The first of these acts by restoring contact between the ends of a divided conductor, thus completing the electric circuit and igniting the wire. But as some unforeseen accident might interfere, and render it necessary to examine the whole arrangement after the mine was laid, a contrivance was added, which after an interval of four minutes would break the circuit again and render every thing safe during examination.

This apparatus is shewn at plate 6, *fig.* 4. It consists of a watch from which the minute hand was removed, and its place supplied by a strip of copper four inches long and a quarter of an inch broad, and fixed by its centre to the arbor of the minute hand. Each end of this index carried by a thread a wire bent thus ∩, the legs dipping into glass tubes fixed in wood, and containing a portion of mercury. As the copper index revolved, its advancing arm, gradually lowered the bent wire *a, a,* into the tubes, and thus established contact with the battery, one of the conductors of which *c,* was interrupted at *d* and *e.* The opposite arm, also connected with a bent wire *b, b,* would lift this from a similar pair of tubes after a lapse of four minutes, and thus break the contact should no explosion have occurred.

A glance at the figure in the plate will render the plan at once intelligible.

This apparatus could be set so as to go for any period from one to thirteen minutes. The watch employed cost twenty-five rupees.

The second self-acting contrivance was perhaps the simpler of the two, and depended on the fact, that if the

conductors come into metallic contact with each other between the battery and the platinum wire, the electricity does not reach the latter, and no ignition occurs,—parting the conductors directs the electric fluid upon the platinum wire, and ignition accordingly ensues.

A joint of bamboo, see plate 6, *fig*. 5, about five inches long by $1\frac{1}{2}$ in diameter, capable of holding 2lbs. of mercury, was fitted with a small brass stopcock below, through which when opened the mercury might escape. It was found by experiment, that when fully open 2lbs. escaped through the stopcock employed in a few seconds more than five minutes.

The bamboo joint was fixed on a wooden frame *f, f*, having a vessel below to receive the mercury. A stout copper wire was led through the diameter of the bamboo, one and a half inch from the bottom. A similar wire was inserted three-fourths of an inch below, and in the same direction with the first, and this second wire was divided into two parts, as shewn in the drawing. The ends of the wires were turned into a few loose spirals to allow of their being readily connected with the battery *B* on one side, and with the conductors to the mine *M* on the other.

Suppose this joint filled with mercury, the stopcock shut, and the battery wires connected with it at one side (say the right), and the mine conductors connected with it at the left—in this case metallic contact being established by the mercury cell in the conductors *c, c*, between the battery and the mine, no ignition can possibly occur—because the electricity returns to the battery by the first cross road it meets, if I may be permitted to use this homely, but I think expressive, illustration.

If we now open the stopcock and allow the mercury

to trickle out, as soon as its level subsides below that of the highest copper wire, the only path for the electric fluid now lies through the mine, the platinum becomes ignited, and explosion ensues.

But should any accident have occurred, so that no explosion takes place at once, and should therefore the whole arrangement need inspection, the mercury still subsiding passes after two or three minutes below the second wire, which having been previously cut, the circuit is now completely interrupted, and the whole arrangement is perfectly safe for inspection.

In using this apparatus two things must be attentively borne in mind. No accident can happen while it is full of mercury, but when once emptied it must not be filled again while in connexion with the battery, otherwise an explosion may ensue.

The whole arragement is shewn in plate 6, *fig*. 5, in which *a* represents the battery, *b* the bamboo mercury cup nearly full of mercury, *c c* the battery conductors, *ć ć* the conductors leading to the explosion tube *t*, containing the platinum wire and priming.

The whole cost of this apparatus, including quicksilver, is not more than six rupees.

It is obvious that many substitutes for the watch apparatus may be devised, and indeed the expense of even the cheapest watch procurable (ten rupees) is an objection, though an insignificant one, to its employment, where circumstances render it advisable to expend all the apparatus by placing it immediately over the mine.

Since these experiments were published and in a subsequent explosion for the destruction of a part of the same wreck, Lieutenant Baird Smith of the Engineers, has

contrived a very ingenious method for accomplishing the same object. His apparatus consists of two pieces of port fire, one half the length of the other. The short one supports the connecting wire by a thread and when this is burned through, the wire falls and completes the circuit. Should explosion not take place in the mine, when the longer port fire has burnt down a weight is liberated which breaks the circuit again and allows safe approach and examination.

I cannot give a better practical illustration of the application of the preceding facts and contrivances than by extracting the following passage from the narrative I published in January, 1840, of the explosion of the "Equitable" in the Hooghly.

Explosion of the barque "Equitable."

"The barque "Equitable," bound to Sydney, and laden with wheat, rice, rum, &c. while proceeding down the river in September, 1839, touched on Fultah Sand, and instantly turned over in six to seven fathoms water. The wreck lay on her beam-ends athwart Fultah Channel, the keel towards Calcutta. On sounding with the lead, the water over her quarter shoaled to three fathoms, and then suddenly deepened to five or six.

Capt. Fitzgerald, the engineer officer employed, determined to attempt the destruction of the vessel by the explosion of 2,500 lbs. of powder placed between the mizen and main masts, close to the deck.

The cylinder already described was admirably fitted up, under Captain Fitzgerald's directions, in the arsenal of Fort William. Before being filled with powder, the exploding tube was screwed into its side, twenty-four barrels of powder were then poured in through an aper-

ture left at the top of the cylinder, which was afterwards closed with wood, *soldered up* with sheet lead, and the security of the platinum wire tested by the galvanometer (see page 59) and a single small and weak cell.

The cylinder thus prepared was slung on a cradle to the bows of the "Vulcan" anchor vessel, which proceeded down the river and took up her berth at Fultah, immediately over the wreck.

At the slack of the tide, on the 14th December, the preparations for lowering the cylinder being completed, the ends of the ladder-conductor were securely twisted to the wires projecting from the explosion-tube, a piece of wood interposed, and the whole guarded by a joint of bamboo and a wedge. As the cylinder was lowered, my assistant, Mr. Siddons, cautiously permitted the ladder conductors to follow, and when the cylinder was in its berth, the conductors were cut short, so as that their free ends should reach the bow of an old fishing boat, previously moored fore and aft over the wreck. To the bow of this boat the wires were secured by twisting them round screws inserted for the purpose; the length of conductors immersed in the water was thirty-four feet.

The battery and watch apparatus were placed on the boat—the watch set to twelve minutes—and, lastly, the battery wires twisted to the conductors at the bow. The party at the mine consisted of Capts. Fitzgerald and Debude, and Lieut. Smith of the Engineers, my assistant Mr. Siddons, and myself. When all was ready, one of the wires in the battery, purposely left out of its mercury cell to prevent accident, was placed in its position, and our party pulled away vigorously from the dangerous vicinity. At the thirteenth minute a

slight concussion was felt in our boat, a sound like that of a very distant and heavy gun at sea was heard, and a huge hemispherical mass of discoloured water was thrown up to the height of about 30 feet. From the centre of this mass there then rose slowly and majestically a pillar of water, intermingled with foam and fragments of wreck, and preserving a cylindrical form till it reached an elevation of at least 150 feet. The column then subsided slowly, a wreath of foam and sparkling jets of water following its descent, and rendering the spectacle one of indescribable beauty.

On pulling to the spot we found the river absolutely thickened by the wreck and cargo of the vessel. By subsequent examination, it was found that with the exception of the forecastle, the "Equitable" had by this explosion been literally torn to pieces. The fishing boat, battery, watch, &c. were all "expended."—The ladder conductors were however picked up uninjured half a mile from the wreck."—(*Journal of the Asiatic Society*, *Jan.* 1840.)

With the cork floating conductors and twelve cells of the gold battery a mine of still greater size may be exploded with perfect safety at 500 yards' distance, the contact being made by the hand and the battery and all apparatus saved. This is the method I would have originally preferred and which has been followed with such signal success by Colonel Pasley in his destruction of the "Royal George," at Spithead.

LECTURE SIXTH.

EFFECTS ON THE ANIMAL AND VEGETABLE SYSTEM—PRODUCTION OF INSECTS.

I have already shewn that the first circumstance known in this department of science was the convulsive effect observed in the limbs of recently killed frogs when pieces of dissimilar metals were brought to act, one on a nerve, the other on the exposed muscle of a limb.

Subsequent observation and experiment have fully shewn that in the living animal galvanic action can excite the sensations of taste, sound, light and touch; can promote most powerfully several important secretions; act generally as a stimulant of great energy, and occasion irregular and convulsive action of the muscular system.

In the dead animal the last class of effects is alone observable. We trace these further in the operation of an analogous influence on those vegetables which possess the power of spontaneous movement.

Lastly, Mr. Crosse has unequivocally shewn the evolution of insects by the excitement of galvanic electricity under circumstances which would defy belief were these not so authenticated as to render doubt impossible.

I shall succinctly examine each of the classes of effects I have alluded to, confining myself for obvious reasons to such explanations as are intelligible to non-professional readers.

Sensation of taste.—A piece of silver being placed beneath, and a similar piece of zinc above the tongue, the instant of contact a powerful and biting saline taste is

perceptible. Some seek to explain this by referring it to a mere stimulating of the nerves of taste, others assert that by the operation of this galvanic couple the saline matter of the saliva is decomposed, its alkalis being evolved at the silver, its acid, at the zinc side. Both causes are probably in operation, but it weighs strongly against the last that the poles of extremely powerful chemical batteries, such as the thirty-six feet cisterns produce less sensation than the single galvanic couple above described. Gold or platinum may be substituted for the silver in this experiment.

Sensation of light.—On placing a silver, gold or platinum plate on the tongue, and a zinc plate between the upper lip and the gum as high up as possible—on the metals touching the sensation of a flash of light is experienced by the eye beneath which the metal is placed. The light is distinct and vivid, but it is of course a mere sensation and shews no external object. This flash is experienced in many other forms of electric experiment, and it has led to numerous attempts at the restoration of sight under the circumstances of blindness being occasioned by want of nervous power; for instance, in the disease, called amaurosis. Although the plan has been very rarely successful, it still deserves a trial in all appropriate cases.

Sensation of sound.—This can only be occasioned by introducing into the ears the poles of a rather strong battery of several alternations, or by one pole being placed in the ear and another between the lips. A harsh grating sound is heard whenever contact is made with the battery. This and other circumstances have led to the use of galvanism in the treatment of deafness. When this malady depends on changes of structure in

the ear the galvanic current can manifestly be of no utility. Where the fault is in nervous debility alone then much good may be anticipated, but such cases constitute but a small proportion of the entire.

Sensation of touch.—Under this head it is probably most appropriate to treat of the sensations occasioned on surfaces deprived of the cuticle, or on wounds, by the contact of galvanic plates or conductors. Pieces of zinc and silver placed on a blistered surface or a wound while separate occasion no peculiar sensation, but the instant they touch the most intense biting pain is experienced. Experimentalists frequently have recourse to this as a test of electrical action, applying the supposed poles to the skin previously slightly abraded.

Influence on secretion.—Several experiments of great importance have been instituted on this subject especially by Dr. Wilson Phillip in pursuit of his favourite idea of the identity of the nervous and galvanic powers. If the great nerves which lead from the brain to the stomach be divided, the secretion of the gastric juice ceases and digestion of course is put a stop to. Dr. Phillip divided these nerves in several animals which had recently taken food, and he then applied galvanic conductors so as to substitute a current of electricity for the nervous influence. It cannot be questioned but that in several instances the secretion of the gastric juice and the function of digestion were renewed. Many physiologists have however doubted that this justified the inference of the identity between the galvanic and nervous agents. They have attempted to shew that merely stimulating the divided ends of the nerves by mechanical or other means led to similar results. For my own part I believe that Dr. Phillip's experiments have been most fairly stated,

and that they unequivocally shew, if not the identity of the two agents, that the galvanic current may efficiently replace the nervous influence for a considerable time and with a degree of efficiency which no other means can approach to.

When Dr. Phillip's experiments were made neither the laws of the battery were understood, nor its proper arrangement known, nor was there in existence a constant and measurable source of galvanic action, such as in the admirable instruments we have now at our disposal. It would be unphilosophical to suppose that such difficulties should not have materially interfered with Dr. Phillip's experiments. The results he gained with his inadequate means and necessarily imperfect knowledge of the instrument he was employing, lend the utmost encouragement to the further and full investigation of this subject. Constant batteries of low intensity but considerable surface should be employed, as while these exercise the greatest amount of chemical and heating power, they are least irritating to the surfaces with which they are brought into contact. In partial imitation of Dr. Phillip's experiments several practitioners have attempted to restore deficient secretions, for example of the liver, by directing galvanic currents or shocks through the parts adjacent to the organ. In several cases this method has been followed by the desired result.

The Galvanic shock.—But the most remarkable and prominent influence on the animal system is the convulsive movement of the muscles excited by this agent. Let us study this effect in some detail.

The first and most remarkable fact we observe is that the effects produced are nearly as energetic in dead

as in living animals, provided the experiment be performed soon after life is extinct.

A frog recently killed may be cut in two and on exposing the nerves leading to the lower limbs, and laying bare one of the muscles of these, contact with a single galvanic couple instantly causes a powerful convulsive movement of the limb.

Fish recently dead placed on copper dishes and touched with pieces of zinc or iron, also touching the dish, are thrown instantly into energetic motion and they struggle as if life had returned.

When we employ compound batteries the extraordinary fact presents itself that a number of very small couples is quite as powerful as those of the largest size. Thus the twelve cisterns of thirty-six feet each produce no perceptible shock, while a pile of fifty pice or halfpence with corresponding disks of zinc, cause powerful commotions of the muscles. By applying the poles of a battery of several couples (say 200) to different parts of the human body, contractions of all the intermediate muscles are observed on each contact. If the battery be constant and powerful the contraction is permanent while battery contact is maintained. Thus on grasping the conductors of 300 of Mullins' cells the hands immediately and irresistibly contract round the handles, and no effort can set them free till the battery circuit be broken: the sensation experienced is equally indescribable and intolerable. It is harmless however, unless too long continued, when such exhaustion must ensue as might prove of the most dangerous or even fatal kind.

In the spontaneously contractile vegetables, such as the sensitive plant and *Hedysarum gyrans*, analogous ef-

fects are observed. In some experiments conducted with Dr. Wallich in 1839, we saw the microscopical moving globules of the *Chara* instantaneously suspend their motion on a slight magnetic shock being transmitted through the water in which the vegetable filaments are placed. The movements soon recommenced and were again arrested as before, on the shock being repeated.

If a chain of several persons, say six, grasp each other's hands, and the first and last take hold of the conductors, it is those who chiefly experience the effects described. The intermediate persons are but slightly affected.

All these effects are produced by the small induction machine described at page 56, and shewn in plate 2, *fig*. 8. Two gold or four copper cells in connexion with this instrument produce effects equal in power to 300 of Mullins' batteries without the coil. Were a giant to grasp the handles of the secondary wire, plate 2, *fig*. 8, his hands would be chained down while the wheel was being turned. The force of this admirable instrument may be reduced at pleasure to a mere sensation of pulsations in the hands, by withdrawing the centre bundle of iron wire or diminishing the number and size of the galvanic cells.

When this instrument is applied to the dead human body the effects to the unhabituated spectator are inconceivably terrific. The arms are flung about, the body starts into the strangest attitudes, the eyes roll and the mouth and features are worked in every variety of expression. These effects I have seen occasioned in the body of a person who had been dead for twelve hours, and from whom the heart and brain had been removed.

The facts I have now described have naturally led to

attempts being made to rescuscitate persons apparently dead from suffocation, narcotic poisons and similar causes. It is impossible to doubt that should a spark of life remain, this stimulant, if any can, will call it into activity. There are very many cases of persons apparently drowned having been thus restored to life, and there would have been many more but for the comparatively cumbrous and troublesome instruments in use until the last few months. The coil machine above described remedies all these defects. It may be put in action in two minutes with the force of a battery of 300 cells.

In the treatment of paralysis, chronic rheumatism, loss of sensation in different organs, and as a general stimulant, galvanism or the secondary coil electricity is resorted to under appropriate circumstances with decided advantage. It must be borne carefully in mind however that it is only applicable in diseases in which the structure of the part affected has not been deranged, and in which there is no inflammatory action. In structural disease or inflammation of a part the use of galvanic electricity will exasperate every symptom.

I forbear for obvious reasons from any description of the celebrated attempts which were made to render galvanic electricity available for the destruction of concretions in the gall bladder and similar organs. The medical student will find this fully explained in my work on Materia Medica now in course of publication. I may here state, however, that the attempt has completely failed, and that there is but little likelihood of its ever proving successful.

In 1832 M. Fabré Palaprat published an account of some experiments apparently well authenticated which if corroborated are of the very highest interest. M.

Palaprat asserted that he had not only succeeded in transferring remedies from the skin to internal organs, but even through one person to a second grasping the hand of the first. He placed a sponge moistened with solution of iodide of potassium in the right hand of *A* whose left hand was moistened with water and grasped by *B*. On *B* being connected with the anode and *A* with the cathode of an active battery, iodine passed from *A* to *B* and was detected by its turning starch blue in the hand of the latter.

M. Palaprat also asserted that he communicated the vaccine virus from one patient *A* to another *B*, by causing *A* to prick the arm of *B* with a needle while both were the conductors of a galvanic series.

He further stated that in more than one experiment *A* being ill of *ague* (a disease neither contagious nor infectious) *B* was caused to suffer from the same malady communicated by electric transfer from *A*.

These singular statements require full investigation. They are put forward with such an air of truth that they claim attention although they do not command belief.

But by far the most remarkable of all the results real or alleged which galvanic electricity has been stated to accomplish, is the production of living insects in Mr. Crosse's famous experiments.

The insect alluded to is a species of *acazus* visible to the naked eye, and which was first observed in the course of experiments conducted for a totally different object. They were seen accidentally on some red *volcanic* oxide of iron subjected to the droppings of a solution of silicate of potash. The salt was prepared by melting at a red heat two oz. of powdered flints (previously heated to redness) with six ounces of carbonate of potash. The

oxide of iron was subjected to the action of nineteen pairs of five inch zinc and copper plates excited by water, on the fourteenth day he saw prominent spots on the stone, and on the twenty-sixth day these were found to be perfect insects with six legs. On the twenty-eighth day they were seen to move about. The same insects were afterwards observed to appear in solutions of several acrid and corrosive salts such as sulphate and nitrate of copper. They occurred in great numbers, as many as 100 appearing in a single experiment.

Mr. Crosse made every conceivable exertion to prevent the accidental introduction either of these insects or their ova into the substances under experiment. A specimen of the insect was submitted to the microscopical examination of the celebrated M. Turpin, the great French Entomologist. He declared that the insect is a *new* species of acarus never before seen by naturalists. This testimony is the more striking as M. Turpin bitterly ridiculed all Mr. Crosse's statements.

Although I have repeated Mr. Crosse's experiments unsuccessfully, and although no other electrician has yet obtained the same results, I cannot but express my entire conviction that his statements are scrupulously true, and that a new insect has appeared in this strange and most mysterious process. Our ignorance of the causes of events can never justify our refusing to admit their occurrence. The more we seek to dive into science, especially where life and organization are our study, the more unfathomable and infinite do its depths present themselves to our view. Wondrous as are the triumphs of the human mind in decyphering the phenomena of nature, a thousand generations each dignified by a Newton or Laplace may fail to penetrate the mysteries which

involve the "creation" of the humblest atom endowed with individual life.

The only hope the mind can reasonably indulge in of light being ever shed on this dark and deep operation, depends on our registering and verifying the facts accumulated by those who are honest searchers after real knowledge. Let us view these facts with the caution which conscious ignorance must dictate, but let us at the same time never refuse to express our belief in their existence, in cringing dread of the ridicule which a presumptuous and false philosophy too often scatters on the humble votaries of truth.

From the whole of the facts I have succinctly noticed in this lecture, it is impossible to doubt the close analogy between vital and electrical operations. The chemical and heating effects of *life* seem as special in their nature and as different from those of ordinary chemical and calorific action, as are those occasioned by the galvanic agent. The power of the will in exciting a muscle to contract is not more intelligible than the same effect produced by the galvanic wire, while in operation the two agencies seem almost identical. M. Donné has recently stated that he has succeeded in causing deflection in the astatic galvanometer (see page 59), by connecting its terminations with the divided ends of the eighth pair of nerves in a large animal. If his statements be correct, and if certain precautions have been observed which will be intelligible when I treat of the electricity generated by heat, M. Donné's experiments fully justify the belief that the production of the spark by nervous influence will soon establish the grand truth of the identity of vital and electric forces. Wherever the galva-

nometer has been deflected the progress of experimental science has soon extricated the spark also, as the history of the magnet and of the electric eel so pointedly shew us. Lastly the power of the eel and the torpedo to generate and accumulate electricity in the manner now familiarly known, lends us additional encouragement in this pursuit. In these animals we behold opposite electricities generated by organs in contact with each other by membranes which under ordinary circumstances do not insulate electric currents. The ultimate tissue and nature of these organs differ in no respect from the anatomical structures of other animals. We have thus the proof that the matters of which the ordinary animal fabric is built up suffice for the generation of electric power, and thus a chief difficulty to our comprehending its possibly constant existence is completely overcome.

I have only further to add a suggestion to those who wish to follow out this deeply interesting inquiry. There are certain poisons, especially nux vomica and strychnine, which produce powerful convulsive movements in animals under their influence. Many facts seem to prove that at the moment of each convulsion an accumulation of the nervous power is as it were suddenly discharged. Let this moment be taken for ascertaining whether the galvanometer needle is deflected, or a spark obtained from Henry's coil (see page 63), if its wire be removed from the surface of the mercury simultaneously with the convulsive paroxysm.

By these tests only can we hope to succeed in accomplishing the greatest discovery which can ever be made regarding the nature of life and organic actions. I shall return to this subject in treating of the electricity evolved by the influence of heat.

LECTURE SEVENTH.

THE GALVANIC TELEGRAPH.

In this lecture I propose to give a concise account of the principle and mode of working of the various electrical telegraphs which have been contrived up to this period. The subject is one of great practical interest, and in its working details perfectly simple.

With this account I shall also embody a statement of results obtained by myself in a series of comparative experiments on a line of wire twenty-one miles in length, which I laid down for the purpose in the Botanical Gardens of Calcutta in May, 1839. Of these experiments an account was published in the Journal of the Asiatic Society for February, 1839.

The first electrical telegraph on record was proposed by Winkler of Leipzig in 1746. He used a Leyden jar which he discharged through a single wire and gave signals by the number of shocks passed from end to end of the line. A similar experiment was made by Le Monnier in Paris with a wire 12,789 feet long, and in 1789 Betancourt laid a wire between Madrid and Aranjuez, twenty-six miles distance, for establishing this mode of communication. Shocks, the divergence of pith balls, and sparks from pieces of tin foil were either used or proposed by various experimentalists as the direct signals to be given.

To all systems of communication by *common* electricity there is this fatal objection, that the wire employed must be perfectly insulated from the slightest contact even of damp air.

In 1807 the celebrated anatomist Soemmering proposed the employment of a galvanic battery provided with thirty-five conductors of indefinite length, each terminating in a gold pin and set in a tube containing water. His object was to decompose the water and let the extrication of gas in each tube correspond to a certain signal. This system however is rendered impracticable by the fact that lengthening the conducting wires beyond very inconsiderable limits annihilates the chemical force of the poles. The compound which of all others is most easily decomposed is the ioduret of potassium, and this in my experiments was unaffected at the trivial distance of three miles from a strong battery.

The deflection of the magnetic needle is the next method resorted to. In Wheatstone and Cooke's telegraph, now in operation between London and Drayton on the Birmingham road, five dipping needles are employed, which require six wires to work them, and which by combined movements of two or more needles give every variety of signal which can be required. The wires are covered with an insulating material and are all placed for security in an iron tube led above the ground from station to station. The cost of each wire is £7 per mile, but including the iron tube the cost is from £250 to £300 for that distance. The needles are affected with scarcely any perceptible interval of time from the making the battery contact at one extremity of the line.

Nothing can be more perfect in its action than this telegraph. The multiplicity of wires is the chief objection to its use. As I shall afterwards point out, two wires at most will suffice for a perfect system of communication, and wherever a railway or canal exists one wire is amply sufficient. Notwithstanding the excessive

delicacy of the galvanometrical needle, it is far inferior still as to the distance for which it acts, to the effects which the secondary coil machine can occasion.

Another description of galvanic telegraph was proposed by Henry of New York in 1838.

This method has attracted great attention, and is said, on good authority, to be in course of practical application in the United States.

Professor Henry proposes to employ the sudden development of magnetism, occasioned in a horse shoe bar of soft iron while surrounded by a spiral of insulated wire, the extremities of which are in contact with a voltaic couple. The magnet thus created attracts a light piece of iron which carries an arm. The arm when attracted marks dots on a revolving cylinder, or may strike a bell. A spiral wire below the centre acts as a spring to lift up the arm on the cessation of each stroke.

Eleven miles of wire were employed in one of Henry's experiments, but the wire was coiled *spirally* round a drum, a circumstance which considerably invalidates the results. This will seem sufficiently intelligible by reference to the construction of the "coil electro-magnetic machine," described in a previous page.

I now proceed to notice the results of the experiments I instituted on the comparative delicacy and efficiency of these and other systems.

My first object was to construct a line of wires of sufficient length to afford practically valuable results. With Dr. Wallich's liberal aid a parallelogram of ground, 450 feet long by 240 in breadth, was planted with forty-two lines of bamboos. Each line was formed of three bamboos firmly driven into the ground, fifteen

feet in height. Each row was disposed so as to receive half a mile of wire in one continuous line, see plate 6, *fig*. 7.

The strands of wire were one foot apart from each other. As each row was laid down, it was carefully coated with tar varnish.

A tent was pitched in front of the entire line, and the connections of the wires were so established that in the course of half an hour it could be tested from centre to the extreme flanks, so as to ascertain the effects of lengths of wire, varying from one to eleven miles at either side, forming a total circuit of twenty-two miles.

The wires employed were of iron (annealed), diameter one-twelfth of an inch. It is almost needless to observe that iron was used not from choice but necessity. The expense of copper wire would have amounted to a much larger sum than I could afford to sacrifice.

With iron wire however I considered that the results would be still of much practical value. Being the *worst* of the metallic conductors of electricity, it seemed a reasonable inference that whatever might be found practicable with iron, would *à fortiori* be so with the copper, or best conductor.

On the completion of the line the following instruments were tried.

1st. An electro-magnet of soft iron, $1\frac{1}{2}$ inch in diameter, poles 1 inch apart, length from centre to poles 12 inches, weight 14 lbs. surrounded by one hundred yards of insulated copper wire, the twelfth of an inch in diameter. This electro-magnet, when excited by the voltaic battery used in the subsequent experiments, with conductors seven feet in length, supported 240 lbs.

2nd. An electro-magnet of very small size, constructed by Watkins, of London, capable of supporting 30lbs. with the battery now referred to, and with the same length of conductors.

3rd. An astatic galvanometer by Watkins and Hill, already referred to.

4th. An electro-magnetic induction or secondary coil machine.

Experiments with the Electro-magnet, No. 1.

The day being fine, the ground and bamboos perfectly dry, at 9 A. M. the sustaining powder of the electro-magnet, No. 1, was tested with iron conducting wires ten feet long, and found to amount to 46 lbs.

With one mile of same wire, ½ mile at each side, it supported, ...	18lbs.
2 Miles of wire, ...	8lbs. with difficulty.
3 Miles of wire, ...	2½lbs.
4 Miles of wire, ...	23 ounces, with difficulty.
4½ Miles, ...	sustaining force ceased altogether.

Electro-magnet, No. 2.

With 10 feet wire, ...	12lbs.
—— 1 Mile, ...	7lbs.
—— 2 Miles, ...	3lbs.
—— 3 Miles, ...	0½lb.
—— 4 Miles, ...	no sustaining power.

Assuming iron to be inferior to copper in about the proportion of 1 to 7, according to Sir Humphry Davy's and Becquerel's standard of conductors, this experiment shews that for equal diameters of wire, copper would convey the signal by Henry's method to about twenty-one miles in an imperceptible period of time. This distance might be extended by enlarging the diameter of the wires, but to what limit, is as yet unknown.

Experiments with Galvanometer.

The astatic galvanometer was arranged and levelled with much care, the needles retaining a very slight degree of directive force so as to cause them to swing in the magnetic meridian.

At	1	Mile, deviation maximum or ..	90°

The needles being restrained by pins at the quadrant:—

At	2	Miles, ...	90°
—	3	Miles, ...	75°
—	4	Miles, ...	63°
—	6	Miles, ...	40°
—	10	Miles, ...	11°
—	11½	Miles at each side = to total circuit 23 miles,	barely perceptible.

Up to the sixth mile the needles were deflected with great rapidity on the connexion being made with the voltaic element. The reversal of the order of connexion also satisfactorily reversed the needle from east to west, and the contrary. But when the deflection fell to below 40°, the movements were exceedingly sluggish, so that on an average two seconds elapsed before each signal could be read off. The change of battery poles then often failed in reversing the direction of the needles—and here, as before, at least two seconds were consumed in each movement. Applying the same rule to this as to the preceding experiment, the galvanometer would convey signals by a similar copper wire to a distance of forty-two miles—and this might be increased by enlarging the wire of the battery, or by adding to the delicacy of the galvanometer.

Induction machine, and mode of correspondence by Pulsations and Chronometers.

The battery was connected with the primary coil, see plate 2, *fig.* 7, by very short wires; and the ends of the

secondary coil wires (plate 2, *fig.* 8,) screwed to the right and left wires of the great parallelogram.

On breaking contact with the primary coil, a shock utterly intolerable passed at half a mile to an individual holding the metallic handles in which the wires ended. By this secondary coil, excited by but three small voltaic couples, the shocks up to seven miles were exceedingly smart—at eleven and a half at each side, they amounted to no more than strong, but not disagreeable sensations. I think these might be best termed "pulsations," for to the *hand* they impart the same feeling proportionately, that a strong and full pulse does to the *finger.*

Of the pulsations thus transmitted, it is perfectly easy to count six in one second—thus with a little practice any signal number can be made from one to six in one second.

Thus with copper conductors equal in diameter to the iron wires I employed, signals by pulsation are proved to be communicable by the method above described, in less than any appreciable period of time, to the distance of 154 miles.

The system of correspondence which I conceive to be the simplest and most effectual is to place at each extremity of the line of two wires, an induction machine and a chronometer. The dial of the chronometer is moveable and laid off with three concentric circles, each divided into twenty sections numbered and lettered as partially shewn in plate 6, *fig.* 8. The second hand only of the chronometer is employed. If these instruments be accurate enough to keep time together for one hour the moveable dial allows of a perfect adjustment being made so that the second hands are invariably

pointing to the same letter or number at the same time, and thus the attention of the observer has only to be aroused at the proper moment in order to give the desired signal.

This system of correspondence can be learned in half an hour. The observer has but to make himself familiar with two classes of sensations in the hands, as distinct from each other as the roll and tap of a drum are to the ear.

The *roll* is given to a person holding the handles attached to the secondary coil, by rapidly turning the ratchet wheel of the first coil.

The *tap* is given by breaking contact suddenly, which is effected by pressing a metal spring (exactly like a flute key) placed in the primary circuit.

Two persons are stationed at each terminus, one say at Calcutta, the second at Agra; one passes the signal, or records it when given to him—the second grasps the handles, observing the chronometer dial, and at the same time he announces the signal to the other.

The annexed memorandum of instruction will explain the rest.

KEY TO THE ELECTRIC TELEGRAPH.

Attention. A roll lasting one minute from A, and returned by B.—

Adjust Chronometer. (This is done by B only. A's chronometer remains untouched.)

1.—*B* sees when the second hand passes 60, or zero, on the dial plate, and he then gives one beat, or tap.

2.—Should this beat be in advance of A's 60 mark, A gives the number of seconds so in advance in quick time and *B* adjusts accordingly.

3.—Should the beat be behind A's 60 mark, A gives the number of seconds so behind in slow time and *B* adjusts accordingly.

4.—When both zeros correspond, A passes three rapid rolls to signify—*All's ready.*

Correspondence.

After adjustment of dials the correspondence is by numbering unless signalled to the contrary.

The spelling signal is given by several rapid rolls made in quick succession.

Both in spelling and numbering,	1 beat indicates,	circle next the hand.
	2 ,, ,,	middle circle.
	3 ,, ,,	outer circle.

It may startle belief but it is nevertheless strictly true and proved to be so by experiment that, the progress of the electric influence through a copper wire in these signals is swifter for equal distances than that of the sun's light through space. In one second it travels 244,000 miles.

Water conducts these signals with diminished rapidity, but still so rapidly that in less than a second of time the influence would pass through a longer line than the circumference of this globe.

A single insulated wire suffices for this method of correspondence, where a river or canal is available, as the second conductor. In one of my experiments at the Calcutta gardens the electro-magnetic machine was stationed at the ghât of Bishop's College, and one of its wires, but twenty-five feet long, dipped in the Hooghly at the ghât. The second wire ran along the dry pathway through the Botanic Gardens, and terminated in

Dr. Wallich's library. A wire led from the river at the ghât before Dr. Wallich's house, also into the library. The assistant stationed at the machine was directed to make the signals in the usual manner. Every signal told in the library without any notable diminution of effect.

It made no perceptible difference whether the tide was ebbing or flowing,—in several trials even the damp mud conveyed the signal unaltered in force or character.

The distance by water in the above experiment was 7,000 feet. In a second set of trials the machine was placed at Sir John Royd's garden, the water distance intervening being 9,700 feet, and with the same results as before.

In a third trial, seven miles of wire were disposed round the trees of the Garden, taking in its entire boundary—starting from Dr. Wallich's house and terminating in the river at Howrah; a second wire was carried from the river, at the west end of the Garden (two miles of the Hooghly being interposed) and proceeded to the north extremity of a canal 3,000 feet in length; from the south end of the canal a wire returned to the library. Thus we had altogether eleven miles of metallic, and 13,256 feet of water circuit, the latter in two interruptions. The signals still passed as intelligibly and strongly as before.

I have already stated that the cost of wire is about seventy rupees per mile. Under all circumstances one wire must be insulated, and of course according to the nature of the line along which the telegraph is laid various precautions would be requisite to ensure its safety. Burying the wire in a trench rammed with pounded brick and mortar would doubtless give both insulation

and security to the extent required. A copper wire would last for many centuries even if exposed to the bare earth as has been sufficiently proved by the condition of the copper plates (tamba patrás) disinterred from various localities in India. At every ten miles the wire should rise through the ground in a masonry pillar to allow of the detection of the situation of accident from earthquakes or similar casualties.

Wherever a railroad exists the rails can be used as one conductor, and the second wire may be buried in the road without insulation. Thus in laying out a railway of the common kind it will cost but £7 a mile, extra, to make the railway the most perfect telegraph ever yet devised. It will give signals by night or day, under every circumstance of weather, from the clerk in his closet to another at his desk, and in every conceivable variety of correspondence systems. More swift than the velocity of solar light, electricity thus annihilates space as an impediment to the communication of ideas, and leaves the time of perception of the signal as the only source of delay.

It has often occurred to me that in India we might for the conveyance of mails and despatches, construct at a very trivial cost a single rail along which we could transmit our daks at treble their present speed, while as an electric telegraph the rail would at the same time transmit its lightning-like announcements of what it was bearing us along.

A single rail of hollow iron tube, one and a half inches in diameter, supported on wooden posts, would carry a light car for mails or parcels which one man could work at the rate of ten to fifteen miles the hour. Or instead of a tube, common flat bar iron might be laid down on posts with the telegraph wire securely insulated and

buried in the wooden sleepers beneath. A mile of suitable bar iron would cost 176 rupees. The supports, welding, &c. would vary in cost in different parts of the line, but the wood is procurable in most places for the labour of felling.

Two coolies could work a palanquin car on a single rail at a speed of at least 10 miles the hour. The expenditure of £60,000 on such a line along the Bombay road would place us in instantaneous communication with that Presidency, reduce the time of transit for our heavy mails to one-third of its present length, and provide for the conveyance of travellers at the rate of 8 miles an hour at least. This plan of single rails was first proposed by Mr. Palmer, and has been adopted successfully in many parts of England and America, where, for local reasons, or the trivial returns to be anticipated, the vast outlay for the regular double railroad could not be undertaken.

LECTURE EIGHTH.

THE CHARCOAL LIGHT AND ITS APPLICATION TO THE MICROSCOPE, LIGHT HOUSES, ETC.

I have noticed in preceding lectures, that when a powerful battery current is directed through pieces of well burned charcoal these ignite and shed a light of such brilliancy that it transcends every other mode of illumination.

The light produced by igniting lime in an inflamed current of oxygen and hydrogen gases, though so powerful that though not larger than a pea it casts a sha-

dow at sixty miles distance, is inferior in illuminating effect in the proportion of two to three, to the same size of charcoal rendered incandescent by the galvanic battery. By approximative experiments it is rendered quite certain that the light from a pair of charcoal points under the influence of a powerful battery is superior to that of 500 wax lights of the ordinary size.

The charcoal must be of the firmest and densest wood. Box, beech and ebony are superior to all others. It should be prepared by ignition in a covered iron crucible filled with charcoal powder and cooled without the contact of the air. With all these precautions it is nevertheless constantly found that several pieces of each lot are not susceptible of galvanic ignition. Such pieces are generally known by the dull sound emitted on their being thrown on a table. If the sound be ringing and metallic they always answer. In selecting pieces, knots should be avoided as these are often exploded with considerable violence and danger to the apparatus employed, on the galvanic circuit being completed.

In plate 3, *fig.* 7, is shewn a simple arrangement for exhibiting this light. Two tall brass stands are provided with horizontal moveable brass arms, each terminating in a pair of copper clasps. The charcoals, one or two inches long and $\frac{3}{4}$ inches square, are inserted in these clasps and the stands are made the terminations of an extensive galvanic series. The effect is represented in the drawing. With the gold battery of forty-eight couples the splendour of the light was so intense that it completely overpowered the full suite of chandeliers and wall lights in the marble hall at Government House. Their lights seemed extinguished—their very flames were seen in deep shadow on the walls. The

eye could no more endure gazing steadily on the light itself than it could on the sun at mid-day.

The chief difficulties in the practical application of this light depended on the inconstancy of the batteries formerly employed; secondly, on the rapid combustion of the charcoal by the air—and thirdly, on the expense of the galvanic power.

The first of these evils has been thoroughly overcome by the improvements recenty made in galvanic apparatus. By batteries constructed on Mullins', Grove's or my own methods a constant and uniform supply of electricity is at our command.

To obviate the rapid combustion of the charcoal several methods present themselves. In plate 6, *figs.* 9, 10, I have sketched one which has, I may say, fully answered my expectations and given us a simple mode of renewing the supply of charcoal as fast as it is required. Two copper disks (9 *a. b*) three inches in diameter (each formed of two pieces of thick sheet copper kept half an inch apart and the circumference cut in radii or so as form a series of clasps arranged in a circle) are armed with charcoal points all round the circumference. These disks revolve horizontally and at an extremely slow rate, on spindles moved through bevel wheels by clockwork, *fig.* 10. As the disks revolve, fresh surfaces of charcoal are continually presented, and by enclosing the apparatus in a common lantern a steady light can be kept up for an hour or longer. By suitable sliders and binding screws the axle of the bevel wheels can be lengthened at pleasure so as to increase the distance between the charcoals according to the strength of the battery used.

Sir Humphrey Davy many years ago shewed that this ignition of charcoal took place in vacuô, the air being

altogether removed, and that the arch of flame previously described, was much longer in this experiment than when the air was admitted. He did not, however, pursue the subject any further, his attention being at the time directed to his celebrated and successful attempts at decomposing the alkalis and earths. Professor Silliman of Yale College in America, repeated the experiment, and observed that during the ignition in vacuô, the charcoal did not suffer combustion, but that small particles were transferred from one piece to the other assuming a fused appearance. The chemical identity between pure charcoal and the diamond seems to have tempted the American philosopher to attend more to the possibility of artificially preparing these gems, than to study the far more fruitful object of applying the light evolved as a source of public illumination.

In plate 6, *fig.* 11, is a sketch of the vacuum apparatus I now use, and by which I have rendered the light perfectly steady and so entirely manageable that I use it with ease for the exhibition of the splendid phenomena of the microscope. A common air-pump is employed. On the plate of this is placed a small stout copper socket for containing one of the charcoal pieces. A glass jar fits on the bell; on its upper aperture fits a ground brass plate provided with a stuffing box through which moves air tight a copper rod terminating in a moveable clasp at the lower end, and in a binding screw at the other. The second charcoal is inserted in the clasp. One pole of the battery is twisted round the brass work of the pump, the second is screwed to the sliding rod. When this is adjusted so that ignition commences, then exhaust the air by the pump. At each successive stroke the brilliancy of the light increases, until when about half

the air is exhausted (as seen by the height of the mercury in the Barometer gauge) it shines forth with steady beaming fulness. Beyond this exhaustion the light becomes purplish and less fit for illumination.

Two pieces of charcoal have undergone ignition for a whole evening in this apparatus without any sensible loss of weight or any material alteration in their form.

In the plate I have shewn the mode of arranging the microscope on the air-pump stand so as to use this light instead of the lime ball and oxy-hydrogen gases.

A common exhausting syringe may be substituted for the pump—all that is required being when the air is half removed to prevent its re-admission by a proper valve.

There remains now but one difficulty to be overcome; namely, the expense of the electric force. My application of gilt porcelain, at once meets the expense of construction; and that of a mixture of saltpetre and oil of vitriol answering perfectly instead of pure and strong nitric acid, reduces the support of the battery to a very inconsiderable expense, about ten rupees for eight hours, the light being equal to 500 wax lights for that period.

By using a very large and numerous series of zinc and copper cells, say 1000 to 1500, water alone or salt water at most would suffice for the excitement, and a constant light be obtained. The cumbrous nature of the apparatus would however more than counterbalance its cheapness.

As steam is only economical where more than the power of fifty men is required, so the galvanic light will be expensive and inapplicable to ordinary private pur-

poses. But for light-houses, streets and public edifices I do not entertain the slightest doubt of its being before long adopted to the total supercession of the gas-light in which we first exulted but one generation since.

Much still remains open for experiment towards the practical adaptation of this magnificent light. By careful study the quantity of light produced may be found to bear a certain ratio to a given oxidation of zinc, and as the chemical and deflagrating powers of the battery are best exerted in different arrangements of its cells, so may a new order be requisite here. The subject is one in the highest degree deserving investigation, especially by the authorities to whom the superintendence of our light-houses is entrusted.

I have only further to add, that various tints may be given to the rays by previously saturating the charcoal with alcoholic solutions of salts of particular metals ;—muriate of strontian gives a deep crimson—muriate of copper a fine green—nitrate of zinc a whitish blue light. For communicating marine signals at night these facts are susceptible of ready and valuable application.

LECTURE NINTH.

ON THE GALVANIC DEPOSITION OF COPPER AND THE PREPARATION OF COPPER IMPRESSIONS OF COINS, MODELS, ENGRAVED PLATES, ETC.

This new and elegant branch of art has been created within the last year by the successful experiments of Mr. Spencer of Liverpool, Jacobi of St. Petersburg and Professor Van Kobell of Munich.

I have stated in the first lecture, that when a plate of zinc or iron is introduced into a solution of sulphate of copper, the iron or zinc displaces the copper, which is deposited in the metallic state on the surface of the displacing metal.

The like effect is produced by the negative plate of a simple galvanic circle, water and the sulphate of copper being decomposed simultaneously, the hydrogen and oxide of copper are liberated on the negative plate, and there the hydrogen takes the oxygen from the metal which is precipitated on the plate.

If the galvanic action be slow the deposited copper is formed in a dense plate, malleable, ductile and flexible as the best common copper. Four years ago I exhibited at Government House specimens of sheet copper thus prepared, and I then pointed out the facility of applying this fact to the obtaining facsimiles of metallic plates.

All that is necessary in Spencer's method is to place the metallic surface of which we desire a copy, in a strong solution of sulphate of copper. Let a wire lead from the object to a zinc plate of corresponding size

placed in a solution of sulphate of soda or common salt, and let both plates be separated from each other by a membranous or porous earthenware partition. A simple galvanic circle is thus formed, and the deposition of copper proceeds gradually on the negative plate. Fresh sulphate of copper must be added from time to time, and in three or four days a plate of new copper will be formed, in which all conditions of the negative metallic surface will be most accurately impressed. If the negative plate have a design in relief the cast will be in intaglio and vice versâ.

It is essential that all parts of the plate, except that from which we wish to obtain an impression, should be defended from galvanic action. This is best done by a coat of sealing-wax, with which the connecting wire must also be covered.

To obtain the cast of a coin by this method, take the glass chimney of an argand lamp and tie a piece of fine bladder firmly round its wider end. Solder a copper wire by its extremity to the centre of the coin at the opposite side to that which you wish to copy, and coat the soldered side and wire with sealing wax. To the other end of the wire solder a plate of zinc of equal size, *not* amalgamated. Suspend the glass tube in a tumbler with the membrane end within an inch of the bottom of the tumbler; half fill the outer glass with a solution of sulphate of soda, and the inner glass to the same level with a saturated solution of sulphate of copper. Now introduce your plates and wire so bent that the surface to be copied from faces and is parallel to the membrane and about half an inch from it. The zinc plate is to be similarly disposed, and the whole kept in a still dark place. Renew the solutions from time to time and in

about three days a plate of metal impressed in intaglio will be formed on the plate in the inner vessel.

There would be considerable difficulty in detaching the new metal from the surface on which it was deposited, were this not previously and very slightly touched over with olive oil and the surface subsequently wiped clean. By this precaution the plates separate without difficulty.

From this intaglio copy a second and relief impression exactly corresponding to the original coin, is procured by a repetition of the process.

If perfectly clean rolled lead be subjected to the gentle and gradual action of a screw press in contact with other metals or hard wood, it takes an accurate impression of their form. By using lead in this way we can obtain mechanically reverse copies of coins, medals, engraved plates, &c., and then direct copies from the lead by the galvanic process.

Should any difficulty occur in the removal of the plates, the application of a gentle heat to the back of the lead by causing the sudden expansion of this at once effects the separation.

There is no limit to the size of the objects which may thus be operated upon with perfect success. Membranes, leather, thick pasteboard, porous slabs of earthenware and of plaster of Paris—all these substances may be used to separate the two solutions.

Instead of operating with a single pair, another and I believe a superior method is to use a weak but constant compound battery with the usual conducting wires coated with sealing-wax. To the positive, solder a copper plate of any required size; to the negative, solder the metal article you desire to copy; immerse both in a

glass vessel filled with a weak solution of sulphate of copper. The positive copper electrode undergoes solution and its copper is transferred to the negative plate, on the surface of which it forms and from which it receives an exact impression.

This process may be much accelerated, according to Mr. Crosse's statements, by using hot solutions in the cell (not in the battery) and maintaining the heat during the experiment.

Several very ingenious methods have been devised for applying this beautiful process to copying engraved wooden-blocks, seals and other non-metallic articles. I subjoin an account of the most efficient methods.

To copy an engraved wooden block.—Place the finest and softest rolled lead on the surface of the block and subject this to screw pressure. It is found by experiment that a boxwood block of the most exquisite workmanship endures the direct gradual pressure of 800 lbs. to the superficial inch, without the slightest injury to its most delicate lines.

Or, place on the block a piece of new and perfectly clean tin foil; over this a sheet of Indian rubber, and press as before. The tin foil adapts itself exactly to the block. Remove the rubber and pour plaster of Paris on the foil to half an inch in thickness. When this sets it removes the foil with it, leaving an exact reverse impression of the block. Make this impression negative in sulphate of copper and the counterpart of the block will be obtained in metallic copper.

The plates of galvanic copper need not be thickened beyond $\frac{1}{10}$th of an inch. The necessary strength for printing is given by a layer of solder or melted tin, or by cementing to a wooden back by lac and sand.

To copy sulphur or plaster of Paris casts or busts, it is necessary to give their surfaces a coating of some substance a good conductor of galvanic electricity. Plaster casts may be rendered impermeable to water by a coating of boiled linseed oil, followed when dry by one of mastic varnish made by boiling the powdered mastic (*roomie mastikoon* of the bazars) in strong spirits. Over this gold leaf or tin foil may be laid, and on this copper deposited, or a mask may be taken in tin from the bust or similar object, and from this mask a copper impression procured.

Mr. Spencer has lately recommended that the object to be copied be first dipped in a weak solution of nitrate of silver, and while moist exposed to the vapor of an alcoholic solution of phosphorus warmed over sand. Phosphuret of silver is thus formed, which by the action of light becomes metallic. By soldering a wire on this surface copper may be precipitated upon it without difficulty.

For copying a large bust or model, I would recommend the following method.

Prepare a pulp of paper pounded with soft water ; place this material layer by layer on the bust previously oiled; when dry, and of sufficient thickness remove the mask thus formed, varnish the inner surface with a strong solution of mastic, and then gild it, or give it a coating of silver by the plan last described. The metallized mask may then be readily arranged in a galvanic series and will give a true copper fac-simile of the original article.

Engraved copper-plates may thus be multiplied, press work stereotyped, and a multitude of similar objects accomplished. The plan has already been widely adopt-

ed in the English potteries in which several copies of each of their copper-plates are required. In India, where from local causes and the incipient state of the European arts, *wood* engraving for book illustration is unknown, copper relief plates, will now be available and constitute perfect substitutes for the admirable English blocks, like which the copper-plates thus formed can be introduced in the body of each page.

It is obvious that if we were to cover a copper-plate with a thin coating of wax like the common etching ground of engravings, we could deposit by this system a layer of fresh copper corresponding to the places only from which the wax had been removed. Or by painting on a metallic surface with colours and varnishes not dissolved by the sulphate of copper solution, we can form a voltaic plate on which every line of the drawing would exist as in a plate etched or cut by the graver. This constitutes Van Kobell's method.

In short this interesting and beautiful process may be varied in a thousand ways; its results moreover are so certain and its management so little difficult that by itself it will amply repay the time and attention bestowed in studying the principles on which it depends.

CONCLUDING REMARKS.

In the preceding lectures there are several points which I have but very slightly touched upon or altogether passed over, being unwilling by any theoretical considerations to interfere with the practical study of the battery and its effects.

The superiority of rolled or sheet zinc over the common metal depends chiefly on the great purity of the former. The common spelter of the bazar is usually

contaminated with small portions of iron, lead and arsenic, which cause local chemical action to occur upon its surface with such irregularity as to interfere much with its use as an exciter of galvanic electricity.

When a single pair of plates is employed it should be remembered that the zinc is positive within the fluid, and the copper, platinum or gold, negative; but that the conductors from these plates if inserted into an electrolyte shew that they have an electric state different to that of their respective plates. For this and other reasons it has been assumed that the electric force is circulating through the arrangement starting from the zinc through the liquid to the copper, from this along its wire to the zinc again.

In the decompositions which ensue in the decomposing cell, Mr. Faraday believes that the particles of an electrolyte which intervene between the electrodes, are simultaneously polarized, and that it is only the first and last particle in each row which suffers ultimate decomposition. Thus water composed of oxygen and hydrogen will be thus affected, say seven atoms being concerned.

x: *x:* *x:* *x:* *x:* *x:* *x:*
Z | O—H.O—H.O—H.O—H.O—H.O—H.O—H | P

The original disposition of these particles having been

x: *x:* *x:* *x:* *x:* *x:* *x:*
O.H—O.H—O.H—O.H—O.H—O.H—O.H.

The distance between the electrodes exercises a very important influence on the decomposition these produce. Thus at half an inch interval the plates of the Voltameter apparatus, plate 3, *fig.* 5, give between three and fourfold more gas than when placed at two inches interval.

In the battery cells also, the nearer the zinc plate is to the platinum the more powerful is the effect produced.

Galvanic combinations may be formed by many metals. Lead is positive to copper, and acted on by dilute nitric acid it gives a very good and steady arrangement. Cast-iron is negative to zinc, and gives a very powerful battery with zinc and dilute sulphuric acid. But as a general rule it should be remembered the positive plate of the battery should have such affinities as to be powerfully acted upon by the fluid employed, while the negative plate should be entirely unaffected.

As the negative metal (gold, platinum or copper) in the fluid, tends to reduce on its surface the metal dissolved from the positive plate (zinc), one of the chief uses of the membranes or porous earthenware partitions is to resist the metal in its transfer to the negative side. By what means it does so is not very clearly understood. Where sulphate of copper is employed this partition serves the important end of keeping the copper solution from contact with the metallic zinc which would at once reduce its copper. Were the zinc thus coated with copper all action in the battery must at once cease.

The nitric acid and sulphate of copper act exactly in the same manner, conducting the electric current or force freely from the zinc to the gold or copper, and there absorbing hydrogen by means of the oxygen they contain. In nitric acid batteries ammonia is formed as well as water, by the hydrogen and nitrogen entering into combination.

The nitric acid used in a gold battery soon becomes of a grass green color, and has then but little action. It may be strengthened for repeated use by boiling it down to one half its bulk in open porcelain capsules.

When mercury is made the negative pole in contact with a salt of ammonia, the mercury enlarges to five or six-fold its original volume, and becomes of a semi-solid consistence. This is owing to hydrogen and ammoniacal gas penetrating the pores of the liquid metal. Some fanciful writers held it to be evidence of the existence of a metal in hydrogen or nitrogen gases.

If mercury be rendered negative in a strong solution of caustic potash, the mercury unites with the metal potassium forming a true amalgam which may be preserved in close vessels. This amalgam decomposes water at common temperatures. It may be procured cheaply by an arrangement of numerous single pairs of elements, and I feel certain it would, if arranged in battery order with platinum, be found, when acted upon by water alone, to be a most powerful exciter of galvanic electricity.

There is much difference of opinion among experimentalists as to the comparative effects of using different proportions of zinc and copper surfaces. Mr. Mullins and Professor Daniell contended that the zinc may be reduced to a mere rod or strap. Mr. Binks, in a very able paper published in 1838, shewed that the chemical action on the zinc element, of a single pair at an inch distance, is greatest when the copper is to the zinc as sixteen to one; or the zinc to the copper as seven to one. These experiments demand repetition.

In 1839 I found that in my cylindrical batteries the inner zinc cylinders, surface 48 inches, produced the same decomposition of water as the outer cylinders, surface 144 inches.

But when the copper surface was altered, there was then an arithmetically corresponding increase or diminu-

tion in the decomposing effect. I found too that the zinc might be much diminished in surface, the copper being unchanged, provided the form was so altered as to elongate the *outline* of each cell.

Finally, in Volta's original view of the nature of this kind of electricity the contact of dissimilar metals was held to be the cause of the electric action. Faraday conceives this to proceed solely from chemical action attended by decomposition. Decomposition being effected by a single pair of plates shews unequivocally that the contact of metals is not the cause of the excitement.

In the next series of these lectures the subject of common electricity will be practically considered.
